space station systems analysis study

FINAL REPORT (PARTS 1 & 2)
Volume 1 Executive Summary

25 March 1977

GRUMMAN

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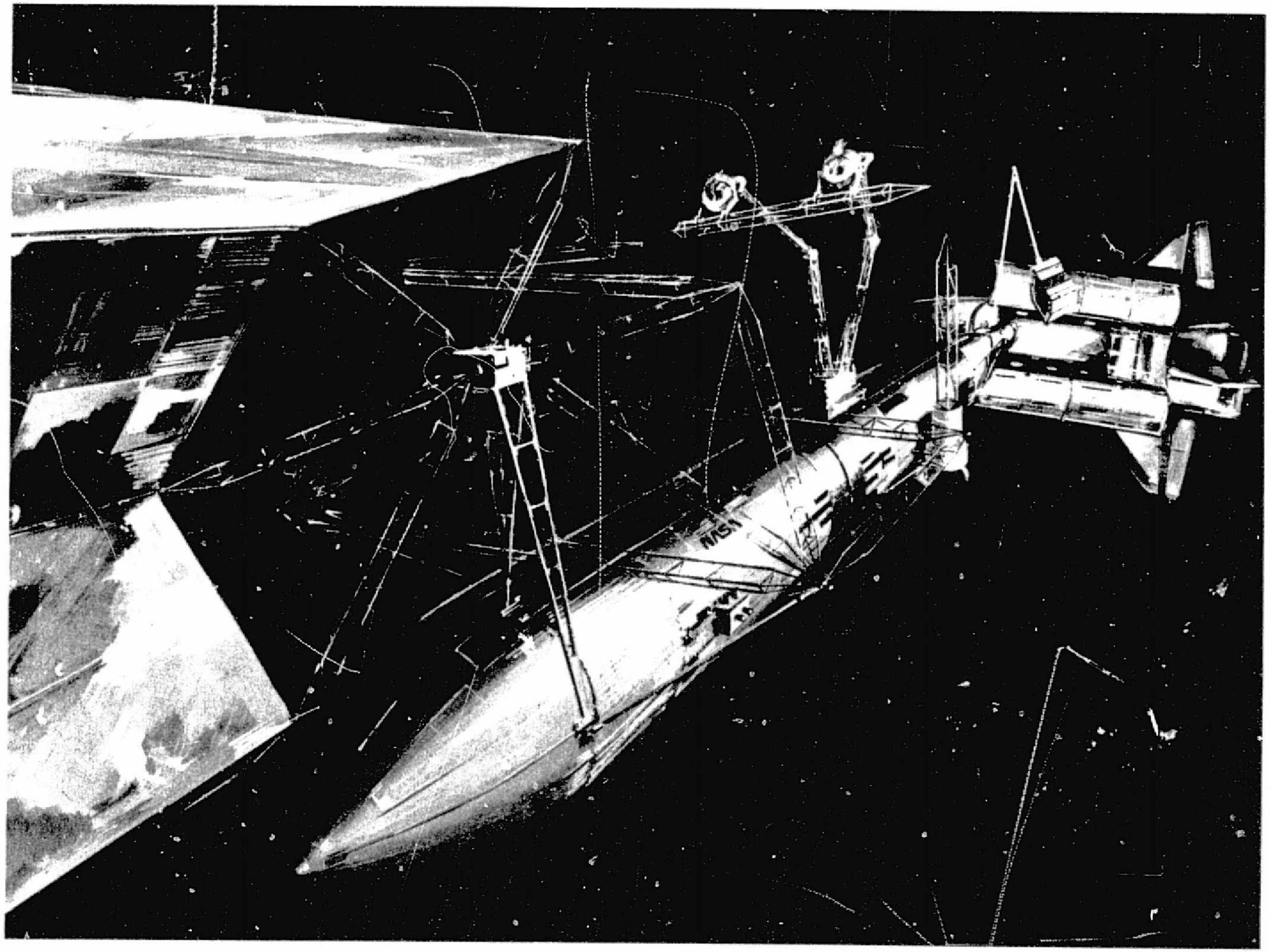
space station systems analysis study



FINAL REPORT (PARTS 1 & 2)

Volume 1 Executive Summary

25 March 1977

Report No. NSS-SS-RP014

Contract No. NAS8-31993

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INTRODUCTION

The purpose of the Space Station Systems Analysis Study is to develop and define the elements of Space Station Programs required to support an operational base theme, a space laboratory theme, and advanced missions relatable to public needs/national interests. The study will identify missions satisfying the foregoing requirements, establish program scenarios/options, and define Space Station, transportation system, and mission hardware functional requirements. System options will be defined and evaluated for a selected number of program options. In depth definition, including subsystem analysis and programmatic comparisons, will be performed for selected primary concepts. The net result will be the definition of effective Space Station concepts oriented towards meeting significant national needs and social requirements, and providing economic benefits.

This study is being conducted in three parts running a total of 15 months, with the last month devoted to the Final Report. These parts include:

Part 1 — Define and Evaluate Program Options

Part 2 — Define and Evaluate System Options for Selected Program Options

Part 3 — Refine Selected Program/System Options

Part 1 started on April 1 and was completed on August 20, 1976. Part 2 was initiated on August 21, 1976 and was completed on 11 February, 1977. These study parts have been performed in accordance with the Study Plan, Grumman Report No. NSS-SS-RP001, dated April 16, 1976, and revised on October 15, 1976.

This report, summarizes the results of Parts I and 2 and represents the first increment of the study Final Report. It consists of four volumes:

Volume 1 — Executive Summary

Volume 2 — Program Options, Book I

Volume 2 — Program Options, Book II

Volume 3 — Missions, Book I

Volume 3 — Missions, Book II

Volume 4 — Integrated Requirements of Space Construction Base

Subcontractor support for this study has been provided by A. D. Little, Raytheon and Spectrolabs. The Final Report for Part 3 will be delivered at the end of June, 1977.

SPACE STATION SYSTEMS ANALYSIS STUDY PART - 2
PROGRAM REVIEW FEBRUARY 9, 10, 11, 1977
VOLUME 1 - EXECUTIVE SUMMARY

DICK KLINE

STUDY STATUS

MISSIONS

PROGRAM OPTIONS

PROGRESSIVE DEVELOPMENT OPTIONS

CONCLUSIONS & RECOMMENDATIONS

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K-315-1

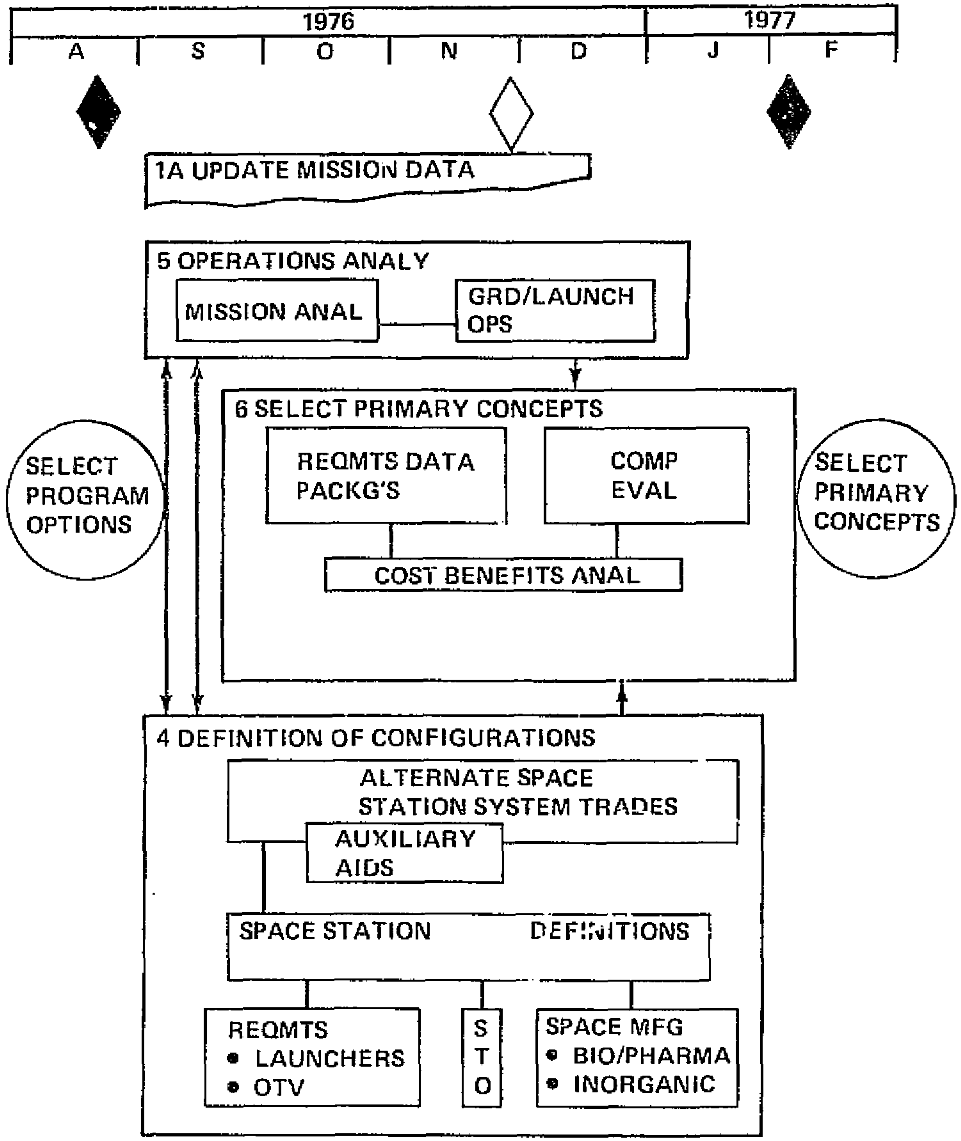
SSSA STUDY LOGIC – PART 2

The Part 2 Study Tasks, as shown on the opposite page, were keyed to program options selected at the conclusion of Part 1 of this study. Within the framework of these program options, configuration definition was developed and concepts selected which best met the requirements of the program options.

A special emphasis task in the area of Space Manufacturing covering the areas of Bio/Pharmaceuticals, Directional Solidification and Crystal Growth was also completed during Part 2.

K301T

SSSA STUDY LOGIC – PART 2



K-301

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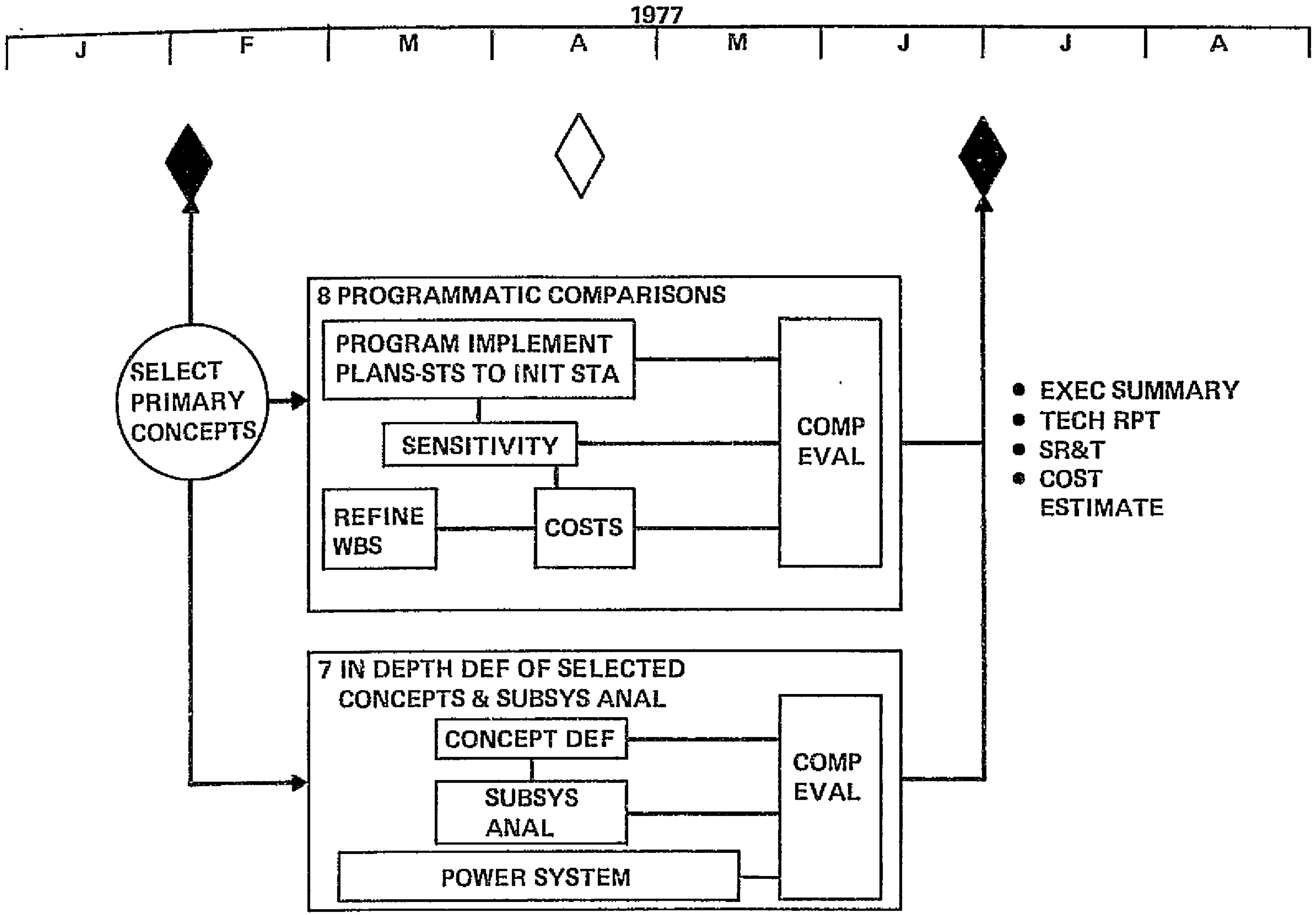
SSSA STUDY LOGIC – PART 3

The planned Part 3 study work will cover definition of selected concepts and subsystems analysis, and refinement of the programmatics and cost data. A special emphasis study of the Electrical Power System will also be conducted.

K302T

SSSA STUDY LOGIC – PART 3



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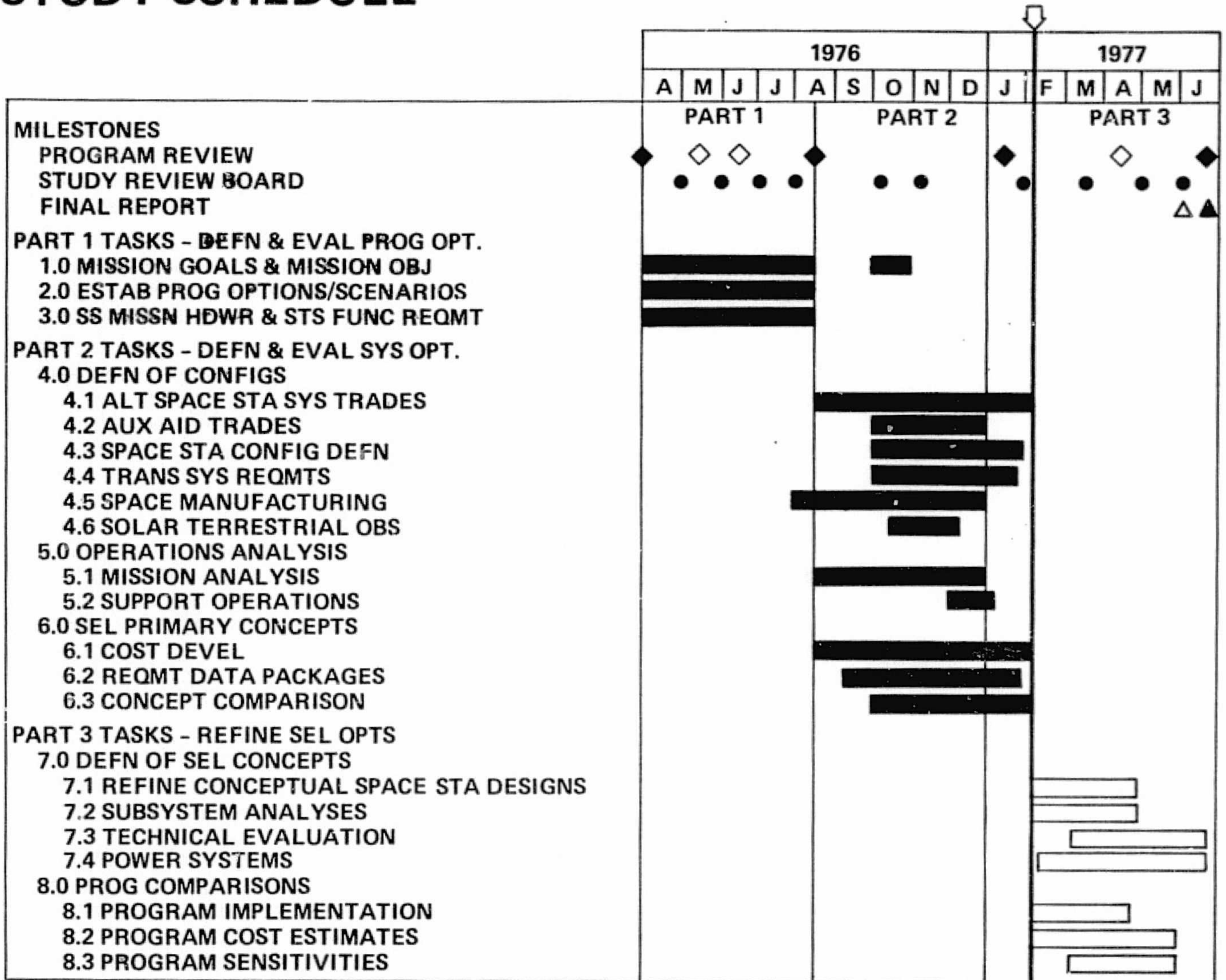
K 302

SSSA STUDY SCHEDULE

The schedule for the Part 2 tasks is shown along with the planned Part 3 work. Major meeting milestones and report schedules are also shown.

K-303T

SSSA STUDY SCHEDULE



K-303

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SPACE STATION SYSTEMS ANALYSIS STUDY PART - 2
PROGRAM REVIEW FEBRUARY 9, 10, 11, 1977
VOLUME 1 - EXECUTIVE SUMMARY

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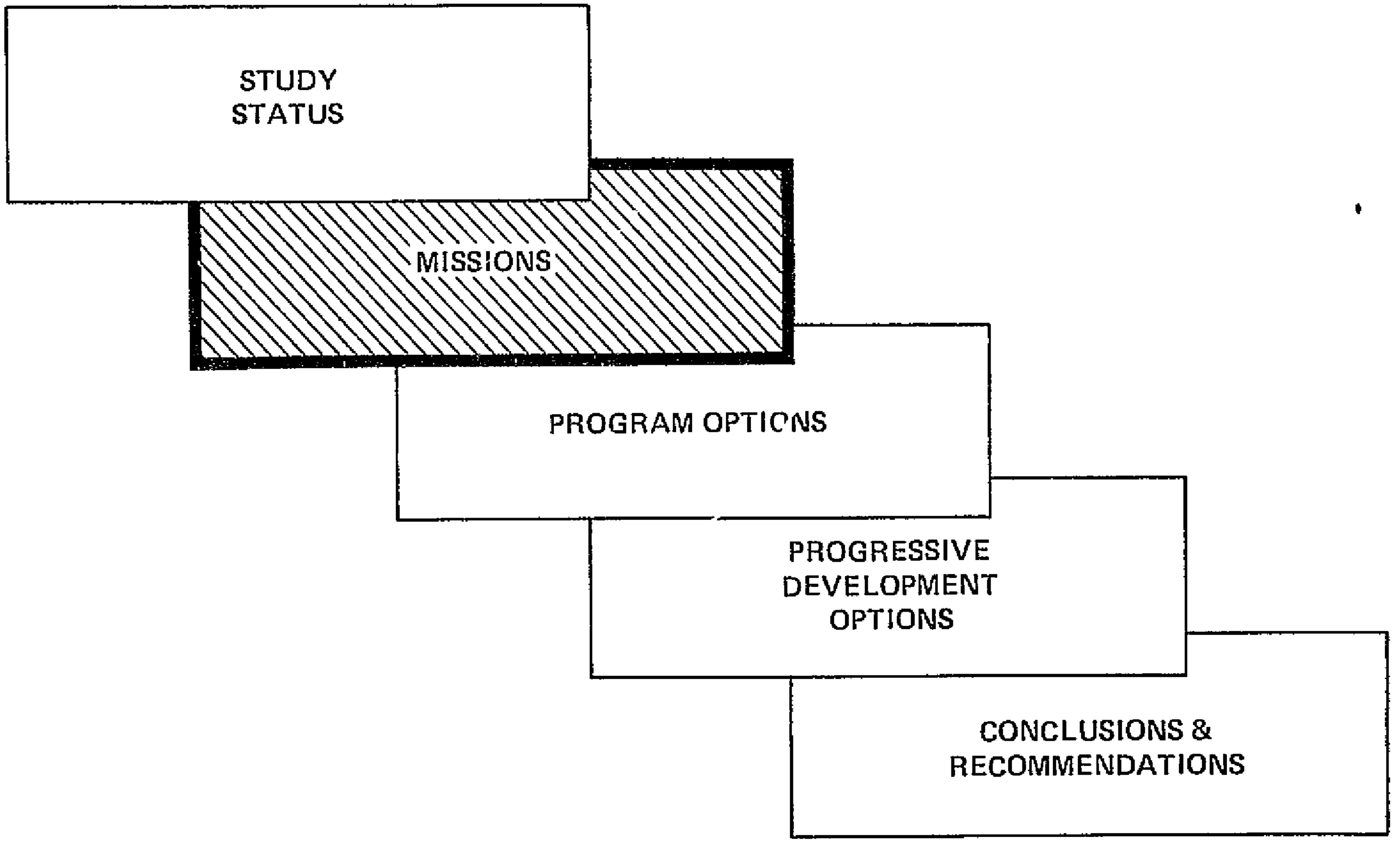

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K-315-2

MISSIONS

Since the Space Construction Base is a means to an end rather than an end in itself, consideration is first given to major beneficial missions which can be implemented by the Space Construction Base.

WHY SPACE SOLAR POWER DEVELOPMENT?

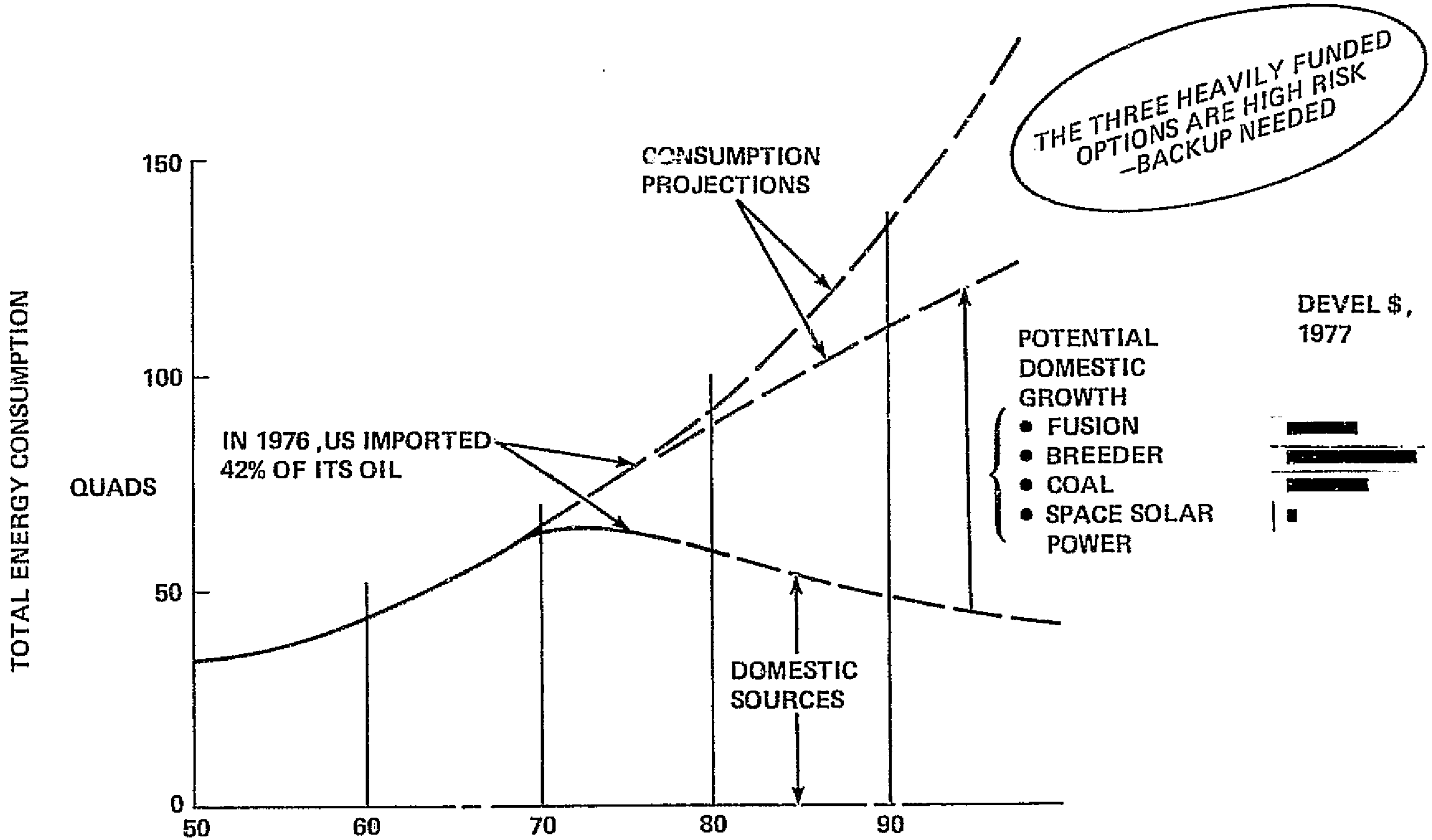
A compelling need exists for the development of alternate power sources. Even with a strong conservation program we must fill an increasing gap between consumption projections and production estimates from our domestic sources.

Space Solar Power is an attractive alternative to the other long term approaches (coal, fusion and breeder reactors). Technical feasibility and economic comparisons indicate great promise for the Space Solar Power options.

Technology development is required to preserve the Space Solar Power options.

JG1T

WHY SPACE SOLAR POWER DEVELOPMENT?



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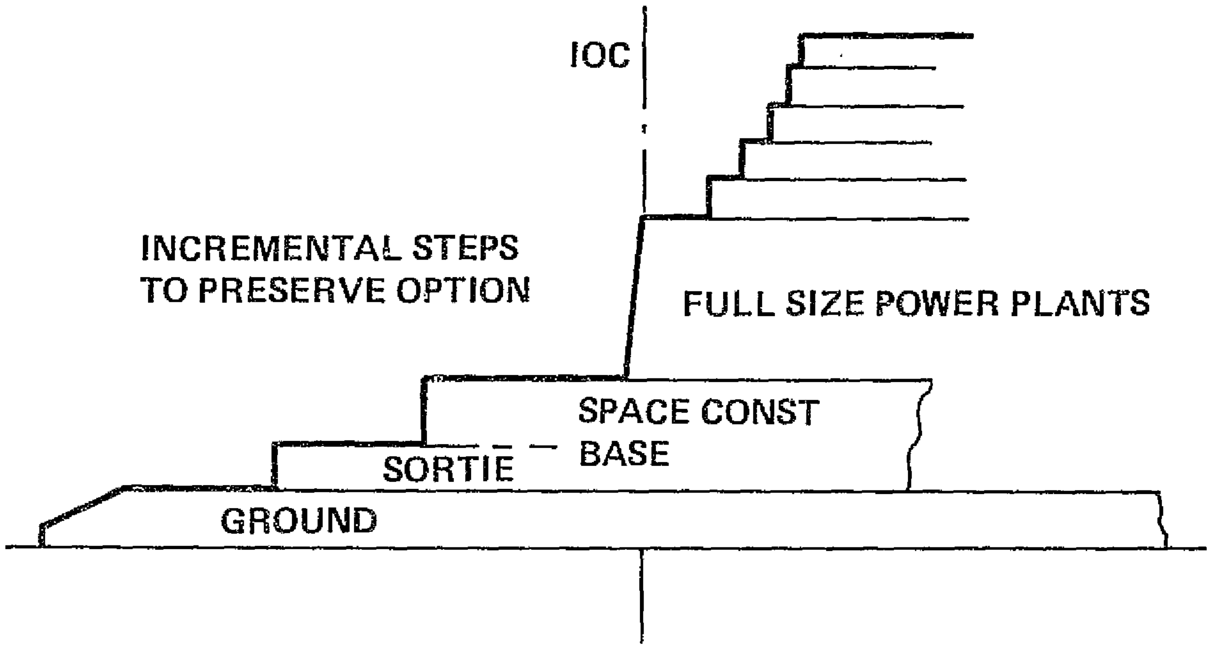
JG-1

SPACE SOLAR POWER DEVELOPMENT

WHY ?

- MAJOR FUTURE ENERGY SOURCE
- ALL WEATHER POWER – DAY & NIGHT
- INDEPENDENT OF FOSSIL/NUCLEAR FUEL RESERVES
- SAFE ~ POLLUTION FREE
- MINIMUM WASTE HEAT

HOW ?



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G-427

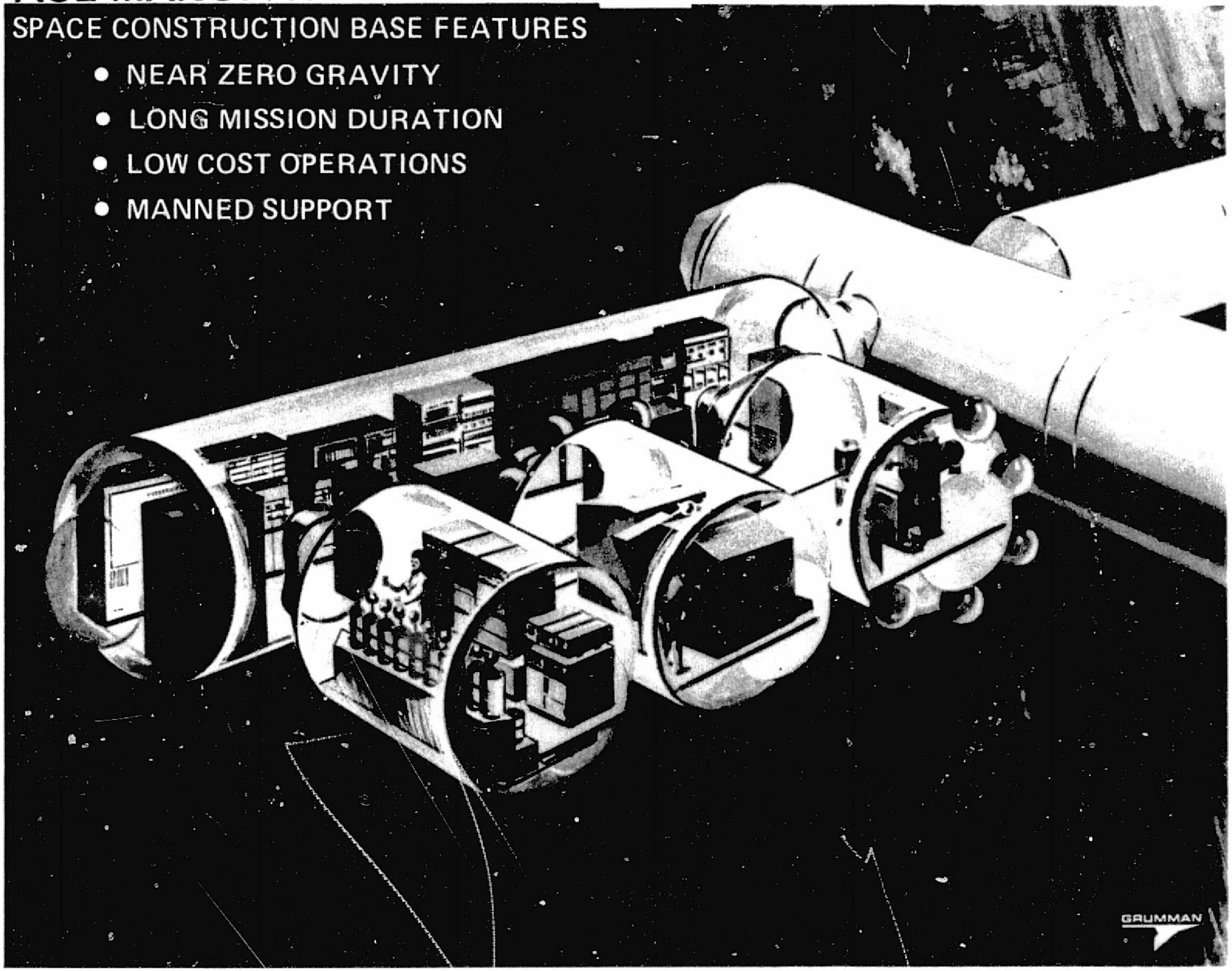
SPACE MANUFACTURING MODULE

Space Manufacturing is a wide category of activity which can capitalize on the facilities potentially available on the Space Construction Base.

Two products were studied in detail: Bio/Pharmaceuticals and directional solidification. The facilities needed to support this manufacture are shown, along with a crystal growth facility which was adapted to the Space Construction Base from other studies.

K322T

SPACE MANUFACTURING MODULE



K-322

SPACE MANUFACTURING POTENTIAL BENEFITS

Benefit analyses were developed for two illustrative space manufactured products, urokinase and high coercive strength permanent magnets.

K321T

SPACE MANUFACTURING
POTENTIAL BENEFITS

PROCESS	ELECTROPHORESIS TISSUE CULTURING	DIRECTIONAL SOLIDIFICATION
PRODUCT	UROKINASE	HIGH COERCIVE STRENGTH PERMANENT MAGNETS
BENEFITS	• SAVING OF 5400 LIVES/YR • THERAPEUTIC TREATMENT FOR ~ 100,000/YR • • •	• 28 B - KWHR SAVINGS FOR ELECTRIC CARS • > \$40M REDUCTION IN A/C IG MAINTENANCE • \$200M REDUCTION IN SPS TRANSPORT COSTS • • •

K-321

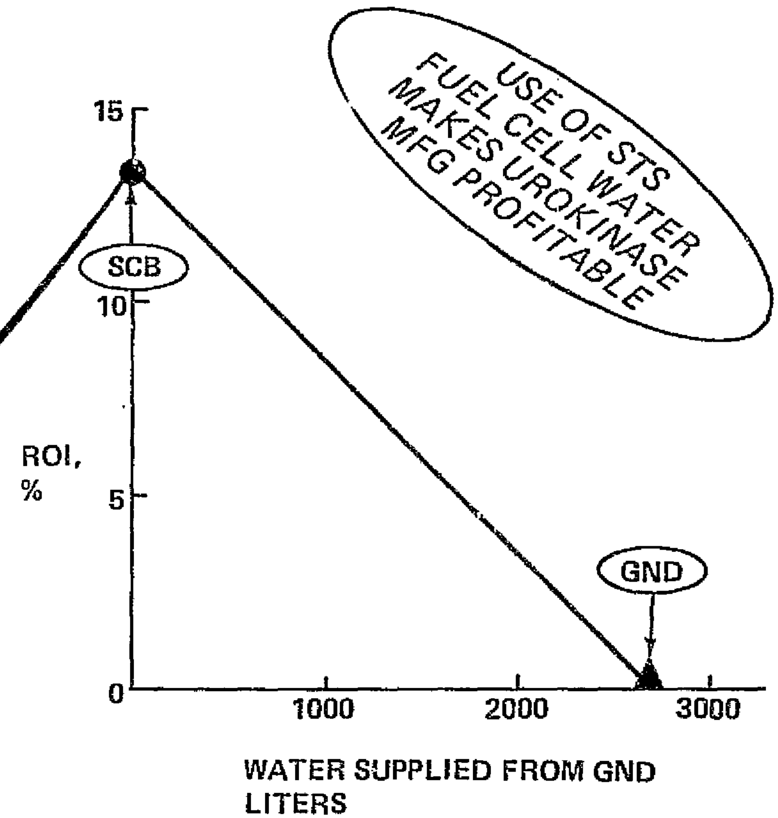
The income statement for the "Spacekinase" Corp. shows that urokinase manufacturing in low-g on SCB can be profitable if used for therapeutic treatment of phlebitis and thrombophlebitis. One of the major factors influencing this profit and % ROI is the availability of water on the SCB. Significant amounts of makeup water will be required because of losses in filters and traps of both the electrophoresis and tissue culturing processes.

Delivery of this water from earth profoundly influences the profitability as shown. If the transportation costs of the required water (at $770/kg) is added to the $0.8M shown in the income statement, the % ROI and profit margin drop to zero.

Fortunately, there is a solution to this water delivery problem — use of excess water generated in the STS fuel cells during a seven day mission, four times a year will supply about 90% of the requirements.

K323T

SPACE MANUFACTURING
UROKINASE PROFITABILITY DEPENDS ON SCB WATER AVAILABILITY



"SPACEKINASE" CORP

INCOME STATEMENT, 1990		
POTENTIAL SALES		20M
OPERATING EXP		17M
DEPREC	1.1M	
TRANS COSTS	0.8M	
OTHER	15.1M	
POTENTIAL ANN. PROFIT (GROSS)		3M
POTENTIAL ANN. PROFIT (NET)		1.5M
ROI:	13.5%	
NET PROFIT MARGIN:	7.5%	

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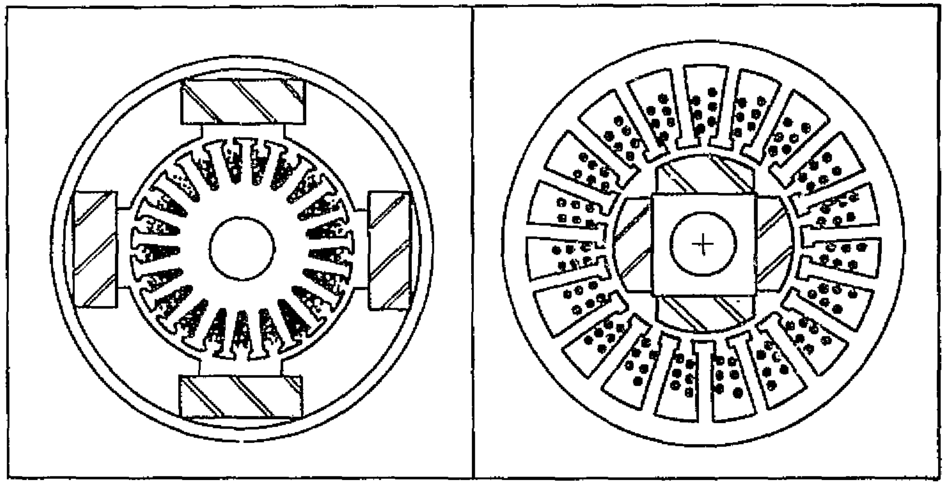
K-323

The electric automobile presents an opportunity to reduce crude oil imports by meeting part of our transportation needs with electrical energy from solar, nuclear or wind-driven generators. A growth to approximately 18 million electric automobiles is envisioned by 2000 AD. However one of the major limitations to this growth has been the unavailability of motors suitable for electric cars.

Until the recent advent of rare earth permanent magnets there was little advantage taken of the performance benefits stemming from the replacement of field-wound magnets in motors with permanent magnets. This was because the available permanent magnets (alnico) are heavy and subject to demagnetization. These shortcomings are overcome with rare earth magnets, so motors of higher efficiency and radically new configurations featuring low weight and small volume are now possible. One such design is the inside-out motor with the armature replaced by a permanent magnet and the windings located on the surrounding stator.

K324T

SPACE MANUFACTURING ELECTRIC CARS POTENTIAL LARGE USERS OF SPACE MAGNETS (SHEET 1 OF 2)



CONVENTIONAL DESIGN NEW INSIDE-OUT DESIGN

- NEW MOTOR DESIGN WITH CoRE MAGNETS REDUCED IN SIZE & WEIGHT, MORE RESISTANT TO DEMAGNETIZATION
- COULD LEAD TO SIGNIFICANT GROWTH IN ELECTRIC VEHICLES

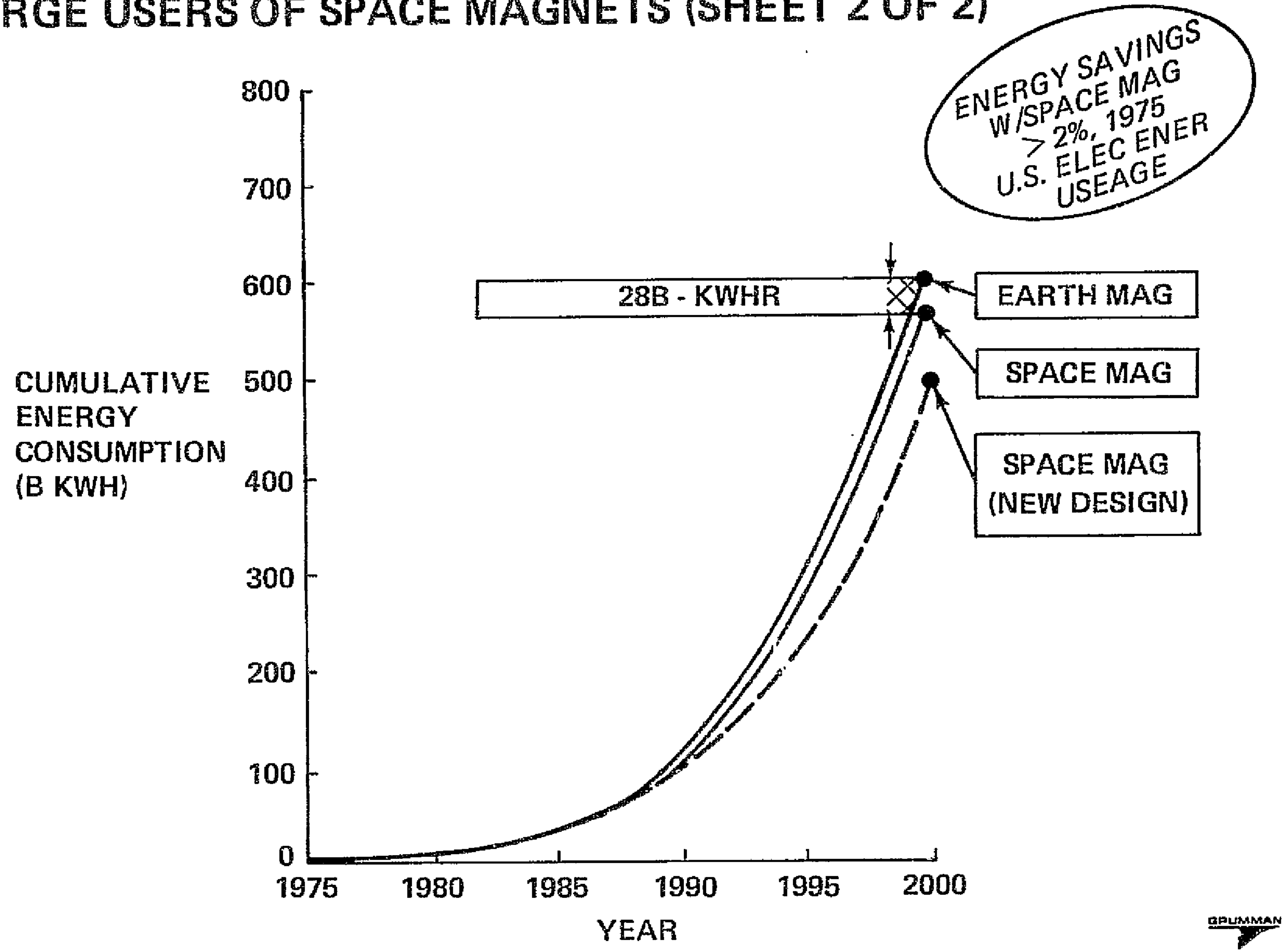
GRUMMAN

K-324

If the wound-field motor of today's electric automobile were replaced by a similar one with space-processed permanent magnets, the consequent improvement in motor efficiency would result in a cumulative savings of 152 billion kwh in the last 15 years of the century. (For comparison purposes, the 1975 US weekly electrical consumption rate ranged between 33 and 41 billion kwh per week). Of this savings, 28 billion kwh can be fairly attributed to space-processed magnets, since about 80% of the 152 billion kwh could be realized with earth-processed permanent magnets. However, there will be other savings attributable to space-processed magnets in addition to those due to motor efficiency improvements, based upon the likely appearance of radically new motor designs beyond the reach of earth-processed permanent magnets. With such motors, new installations and power transmission concepts will be developed, resulting in considerably lighter vehicles and consequent reductions in energy consumption additional to those due to improving efficiency in state-of-the art motors.

K325T

SPACE MANUFACTURING ELECTRIC CARS POTENTIAL LARGE USERS OF SPACE MAGNETS (SHEET 2 OF 2)



K-325

PUBLIC SERVICE PLATFORM: AN INTEGRATED PUBLIC SERVICE CONCEPT

The Public Service Platform is viewed as a means for integrating many public service functions into three lens antennas that are interconnected as one structure. This concept allows the common utilization of subsystems such as attitude control, propulsion and telemetry. The first lens antenna system defined as the early PSP, provides the services in the category of voice/data. This antenna is predicted to be 61 m in diameter, operate at S-band, and interface with a class of users that require wrist radios. The second antenna system provides services in the category of video/data and is predicted to be 18 m in diameter, operate at K-band and interface with a class of users that require an antenna less than 2.5 m in diameter. The third lens antenna provides services in the category of detection/control and is predicted to be the same as the first antenna. Further, it interfaces with a class of users that are sensors with low power beacon transmitters.

In several options, a low-earth-orbit Space Construction Base (SCB) is utilized for the erection, assembly, test and maintenance of each antenna system prior to their launch to GSO. For a GSO SCB similar tasks may be performed.

F379T

PUBLIC SERVICE PLATFORM
AN INTEGRATED PUBLIC SERVICE CONCEPT

WIDE RANGE OF SERVICES COULD BE PERFORMED

- VOICE/DATA
  - PERSONAL COMM
  - POLICE COMM
  - DISASTER CONTROL
  - VOTING/POLLING
  - ETC

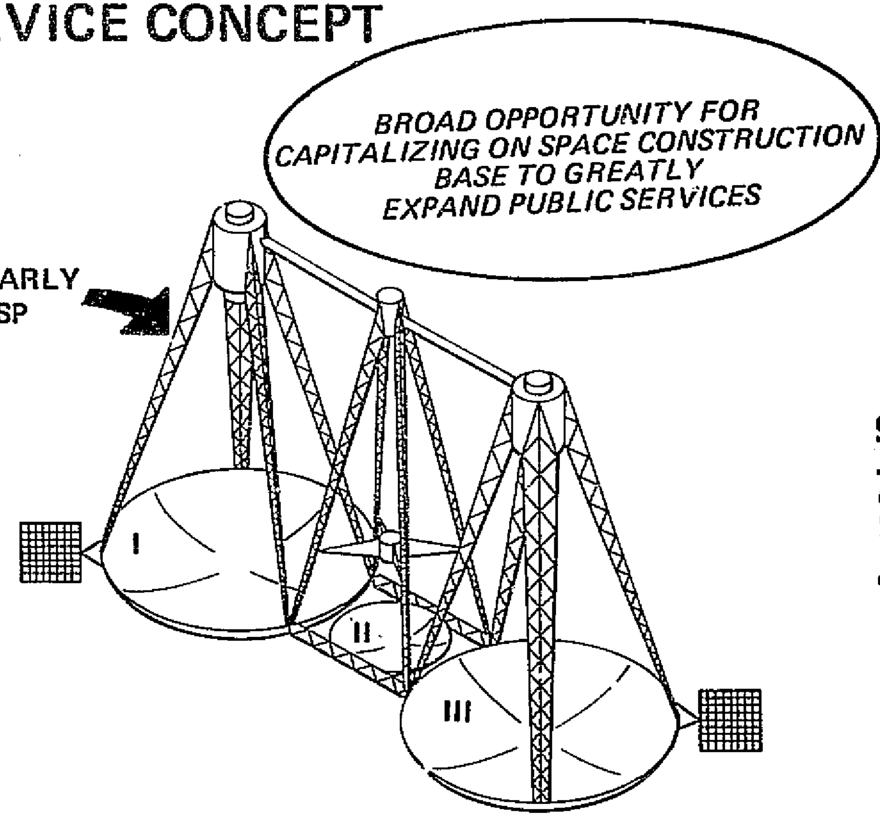
I

- VIDEO/DATA
  - ADVANCED TV
  - TELECONFERENCING
  - ELECTRONIC MAIL
  - NATL INFO SERVICE
  - ETC

II

- DETECTION/CONTROL DATA
  - NUCLEAR FUEL LOCATOR
  - EARTHQUAKE DETECTION/PRED
  - WATER AVAILABILITY INDIC
  - VEHICLE SPEED CONTROL
  - BURGLAR ALARM/INTRUSION DET
  - ETC

III



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K-406A

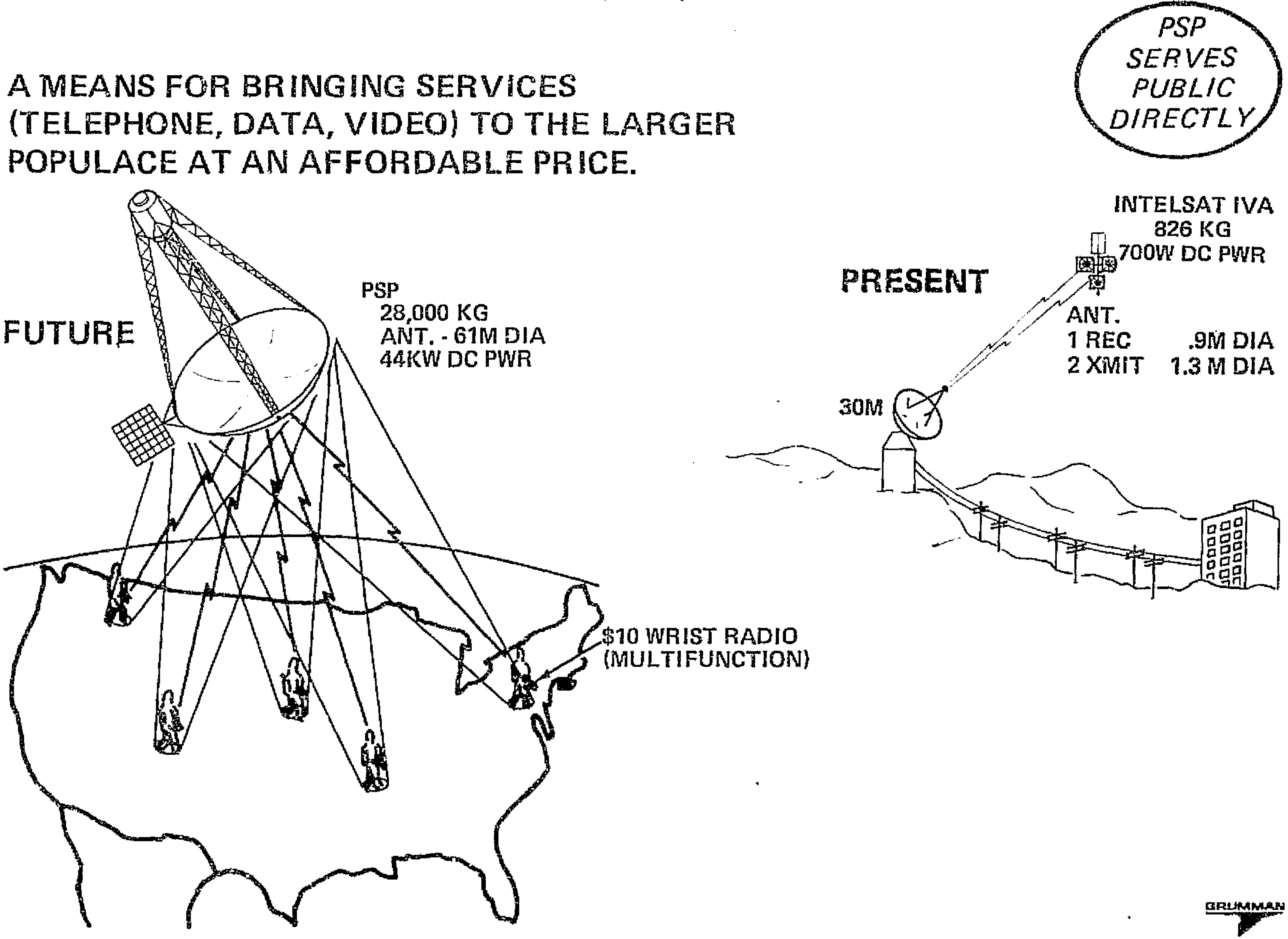
PUBLIC SERVICE PLATFORM (PSP)

The early PSP is compared to the Intelsat IVa, a commercial international satellite system procured by COMSAT Corporation. In operation since 1976, the Intelsat IVa is seen to be a significantly smaller payload compared to the PSP. With smaller antennas, the Intelsat IVa must interface with a large ground antenna (30 m) to complete the communications link. In con- contrast, PSP is a very large spaceborne antenna, and consequently large gain, enabling the ground user equipment to be much smaller. An important limitation of the present systems like the Intelsat IVa is the payload restrictions due to the launch vehicle. For the Space Construction Base, supported by the Space Transportation System, such payload restrictions do not exist.

F305T

PUBLIC SERVICE PLATFORM (PSP)

A MEANS FOR BRINGING SERVICES (TELEPHONE, DATA, VIDEO) TO THE LARGER POPULACE AT AN AFFORDABLE PRICE.



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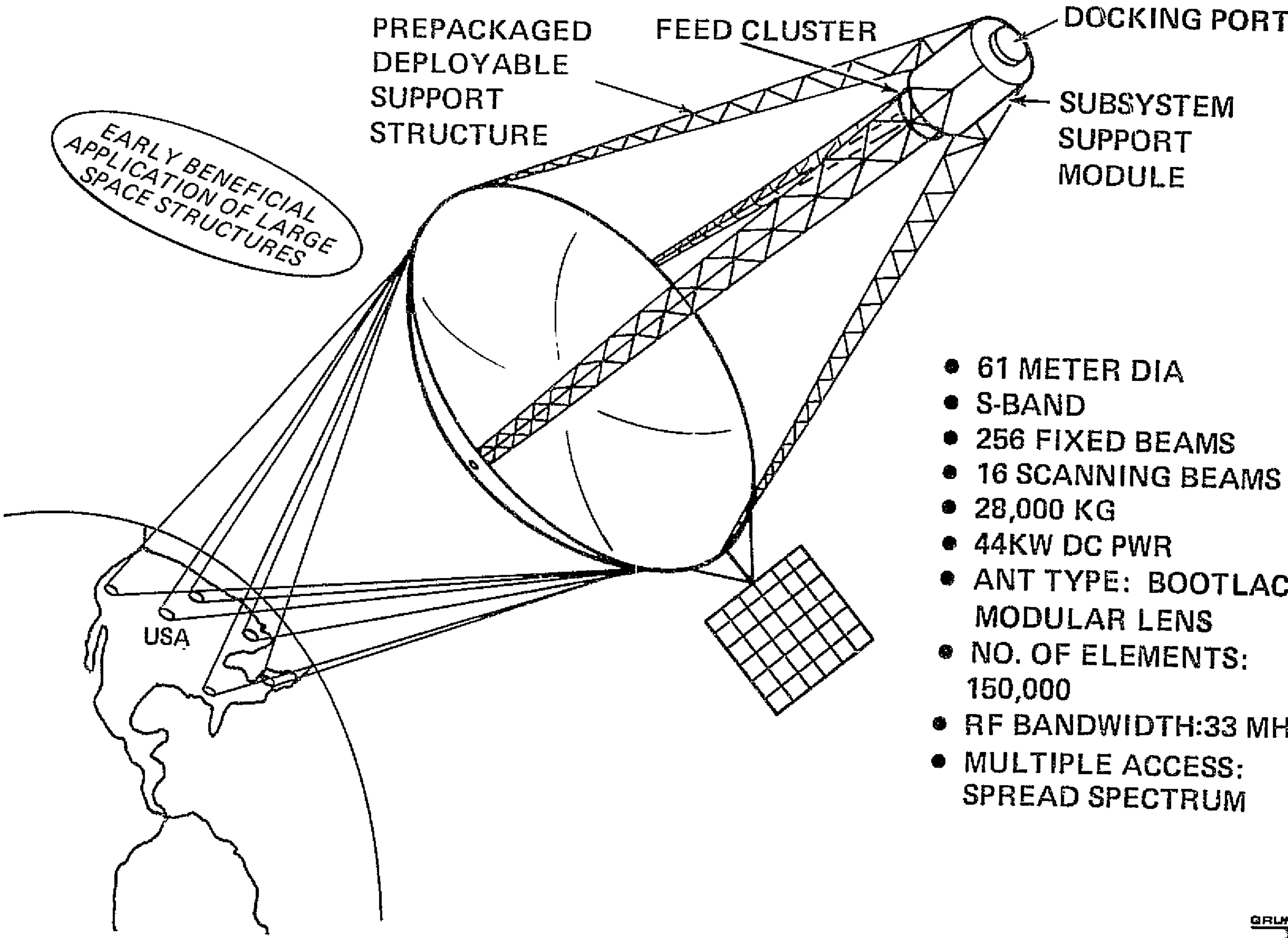
F-305

EARLY PSP CONFIGURATION

Characteristics for the early PSP are summarized along with a configuration description. A modular aperture design, together with subsystem packaging techniques, allows complete ground fabrication. This approach minimizes the number of required shuttle flights. On-orbit assembly is performed using the Space Construction Base.

F-324T and K-311T

EARLY PSP CONFIGURATION



- 61 METER DIA
- S-BAND
- 256 FIXED BEAMS
- 16 SCANNING BEAMS
- 28,000 KG
- 44KW DC PWR
- ANT TYPE: BOOTLACE MODULAR LENS
- NO. OF ELEMENTS: 150,000
- RF BANDWIDTH:33 MHz
- MULTIPLE ACCESS: SPREAD SPECTRUM

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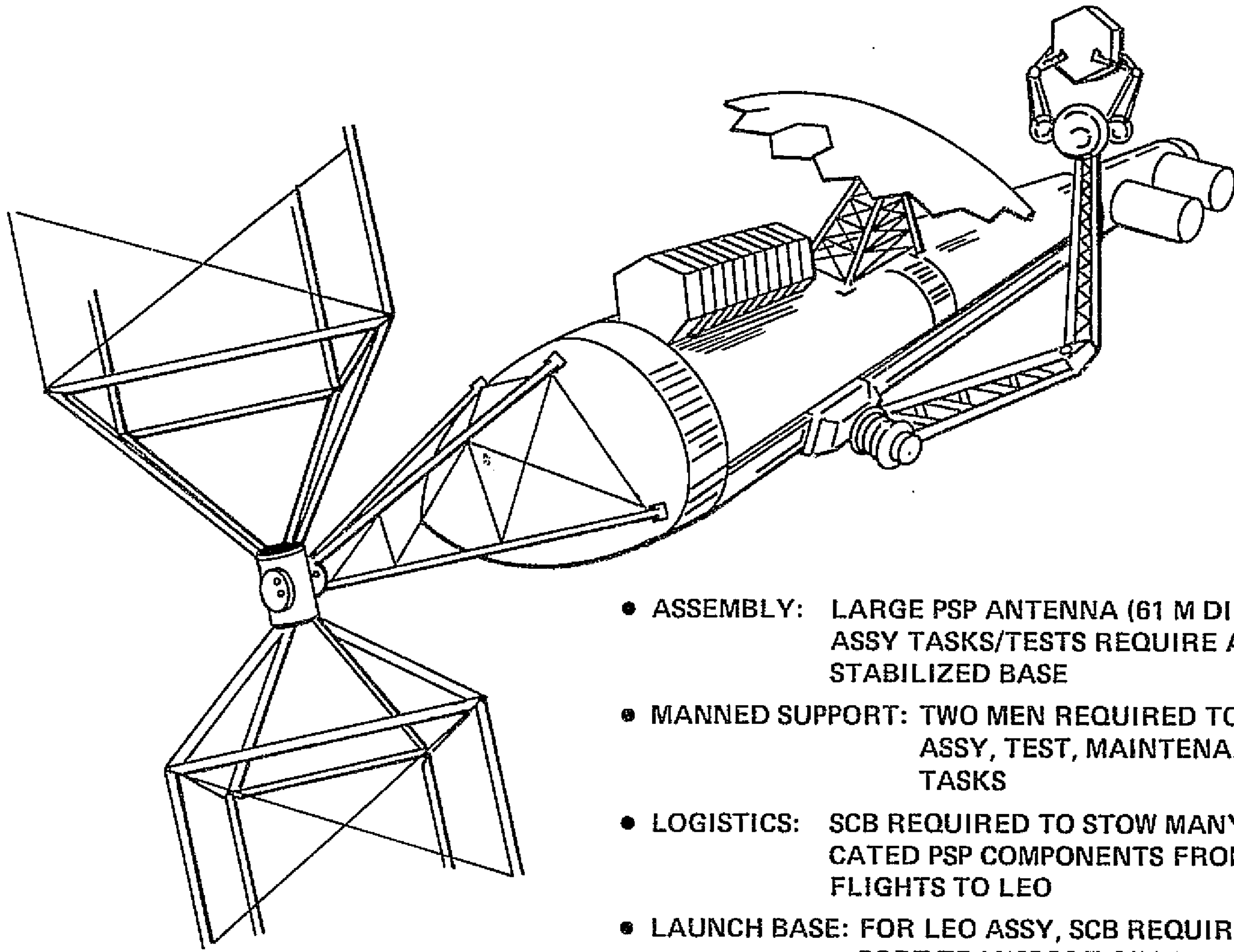
K-311 (F-324)

EARLY PSP ASSEMBLY

A partly constructed antenna for the Early PSP is depicted. The Space Construction Base (SCB) Remote Manipulator, which is man-tended, is carrying an antenna module from the storage rack to be attached to the antenna. The rack of modules was carried to LEO in the STS Orbiter cargo bay. Other PSP requirements which drive the SCB relate to logistic and transport support to GSO.

K405T

EARLY PSP ANTENNA ASSEMBLY
PSP DRIVERS ON SCB



- ASSEMBLY: LARGE PSP ANTENNA (61 M DIA) & MANY ASSY TASKS/TESTS REQUIRE AN ON-ORBIT STABILIZED BASE
- MANNED SUPPORT: TWO MEN REQUIRED TO PERFORM ASSY, TEST, MAINTENANCE & REPAIR TASKS
- LOGISTICS: SCB REQUIRED TO STOW MANY GRD FABRICATED PSP COMPONENTS FROM TWO STS FLIGHTS TO LEO
- LAUNCH BASE: FOR LEO ASSY, SCB REQUIRED TO SUPPORT TRANSPORT OF PSP FROM LEO TO GEO

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F-381

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BENEFICIAL SCIENTIFIC MISSIONS: SOLAR/TERRESTRIAL OBSERVATORY

Extended operation of a space platform such as the Space Construction Base provides an excellent opportunity for systems such as the Solar/Terrestrial Observatory. Compatibility of the STO with the SCB and its various options has been considered. In this first look we saw the low earth/high inclination orbits and the geosynchronous orbits of SCB readily capable of incorporating the STO missions.

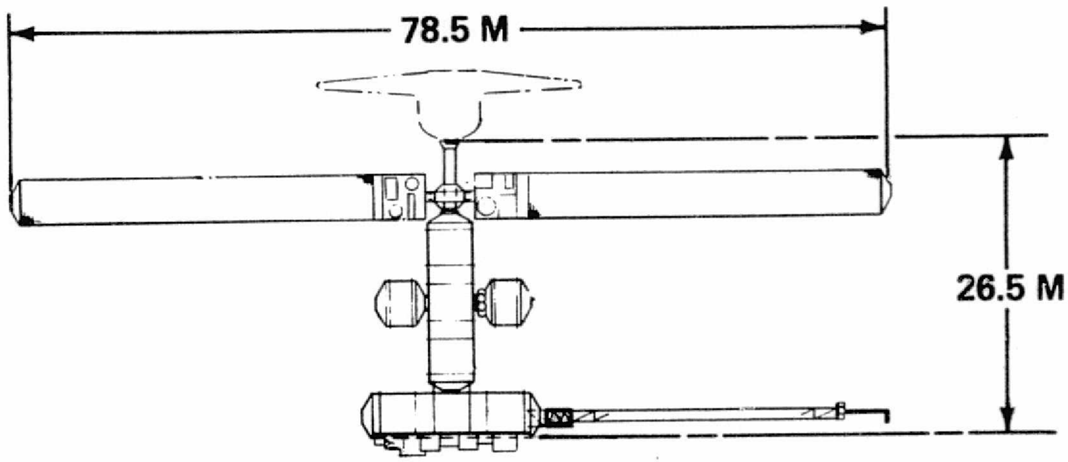
The SCB sketch shows the configuration proposed for low earth/high inclination orbit with the STO related hardware shaded. Note that much of the solar instrumentation is mounted externally on the solar panels to take advantage of the panel pointing system. The rest of the hardware is located internally and externally on a dedicated module located opposite the solar panels.

K-314T

BENEFICIAL SCIENTIFIC MISSIONS: SOLAR/TERRESTRIAL OBSERVATORY

LONG RANGE CLIMATIC PREDICTION

DEFINE A FIRST GENERATION STO (INSTRUMENTATION AND MODE OF OPERATION) WHICH IS INTEGRATED WITH SPACE CONSTRUCTION BASE



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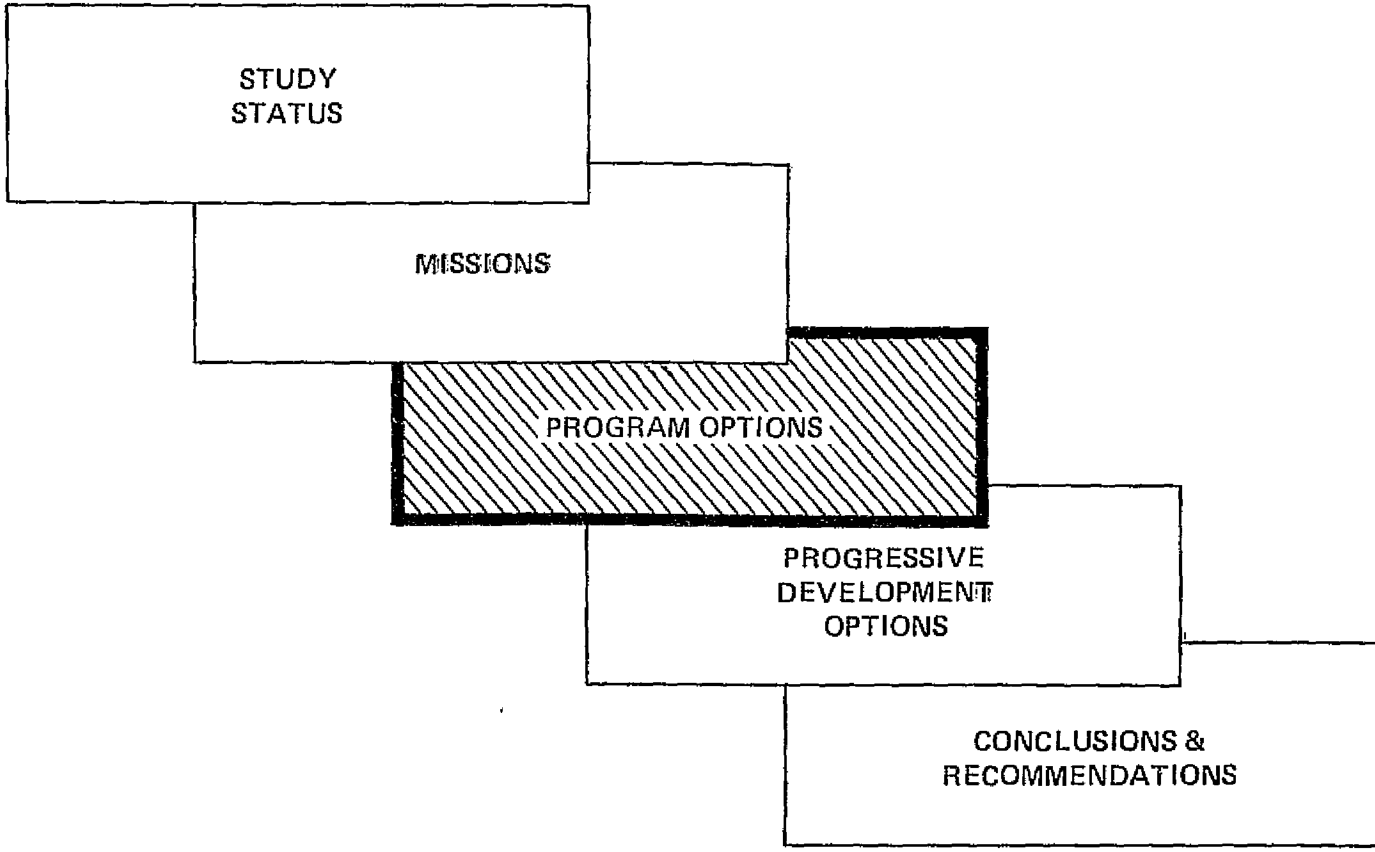

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K-315-3

PROGRAM OPTION – MAJOR CHARACTERISTICS

The Space Construction Base (SCB) program options studied during Part 2 of the study are shown on the opposite page. The program options are grouped by their development provisions for Solar Power Satellite (SPS): One grouping assumes that the full size SPS will be assembled in Low Earth Orbit (LEO) and a second grouping assumes that the full size SPS will be assembled in geosynchronous orbit (GEO).

Option 1A/B has the SCB starting in 1984 with introduction of the Orbital Depot in 1990 to handle OTV flights. A construction base in LEO, dedicated to building SPS, is started in 1990. A space operations base starts in 1993. The difference between 1A and 1B is that a 150 kw SPDA to power the SCB in 1984 is built by sortie flights in 1983 for Option 1A but in Option 1B, that SPDA is built by the SCB as its first task. This difference is too small to appear on the chart.

Option 3 is identical to Option 1A except that an observatory flying in LEO, high inclination, is added to entirely accommodate STO requirements.

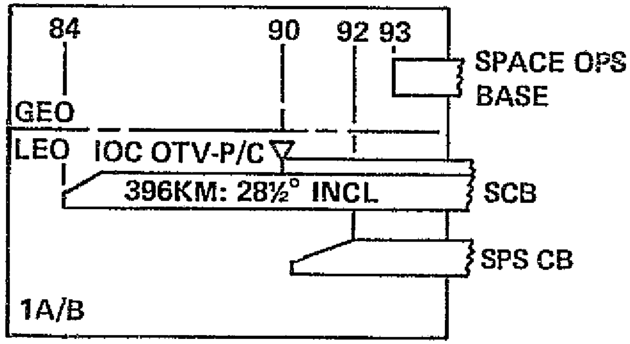
Option 2A differs from 1A in the following respects. The SPS is built in geostationary although its construction base IOC is the same. An SCB to build a 2 mw SPDA in geostationary is commissioned in 1986 which requires that the Orbital Depot to handle OTV's is brought forward to the same year.

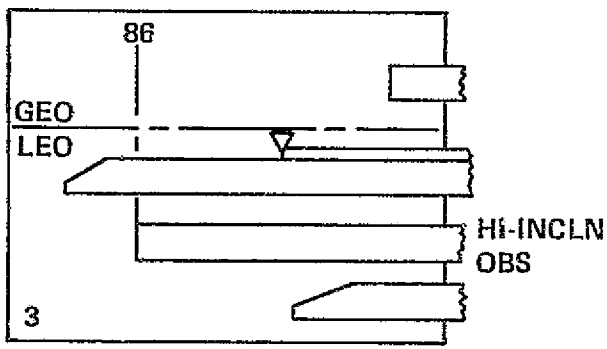
Option 2B is the same as 2A except that the 2 mw SPDA is built in LEO, as in Option 1A. This leads to a minimally operational outpost being provided in 1986 in geostationary to monitor the environment on man as an input to the SPS 'go/no go' decision in 1987. This, in turn, requires the Orbital Depot in 1986.

G-339T

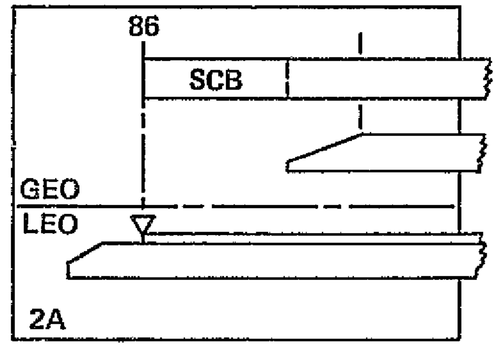
PROGRAM OPTION – MAJOR CHARACTERISTICS

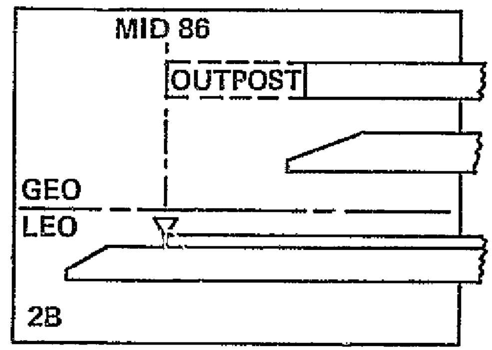
FULL SIZE SPS ASSY PLANNED FOR LEO





FULL SIZE SPS ASSY PLANNED FOR GEO





PROGRAM OPTIONS 1A, 1B & 3

This chart defines the program options 1A, 1B and 3 for the 1984 through 1986 time frame. The subsequent chart continues the definition thru 1991.

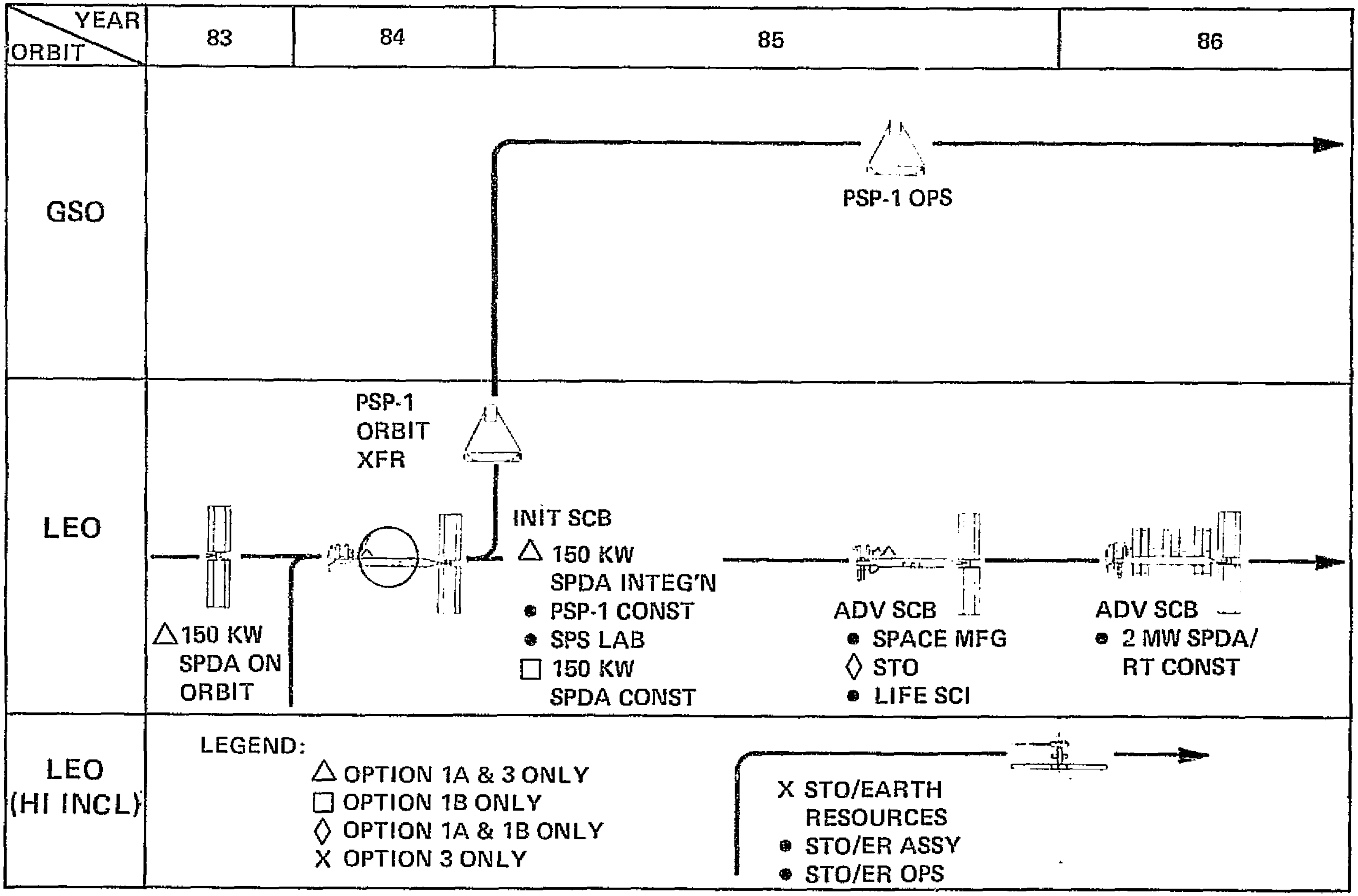
In 1984, Option 1A Initial Space Construction Base (SCB) is assembled in low earth orbit (LEO) and integrated with a 150kw Solar Power Development Article (SPDA) from a prior development program. The first Public Service Platform (PSP-1) is constructed by the SCB, detached and orbited into a geostationary orbit (GSO) where it becomes operational during the first quarter of 1985. While the PSP-1 is being constructed, the Solar Power Station (SPS) lab, which is part of the initial SCB, becomes operational. Early in 1985, the initial SCB is enlarged to an advance SCB configuration and the Space Manufacturing, Solar Terrestrial Observatory (STO) and Life Science (LIFE SCI) activities become operational. The 2mw Solar Power Development Article/Radio Telescope (SPDA/RT) is constructed by the advanced SCB during the second quarter of 1986. It is detached from the SCB and remains in LEO for further tests.

Option 1B definition is similar to Option 1A except for the 150kw SPDA LEO activity in 1984. In Option 1B, the 150kw SPDA is not available from a prior development program and is thus constructed by the initial SCB.

In Option 3, the STO activity is deleted from LEO/28.5 deg and added to LEO high inclination (Hi-Incl). The Solar Terrestrial Observatory/Earth Resources (STO/ER) lab is launched directly from the ground into a LEO Hi-Incl orbit during late 1985. The Earth Resources PSP (part of the STO/ER) is assembled and becomes operational along with the STO early in 1986.

F-382T

PROGRAM OPTION 1A, 1B & 3 (SHEET 1 OF 2)



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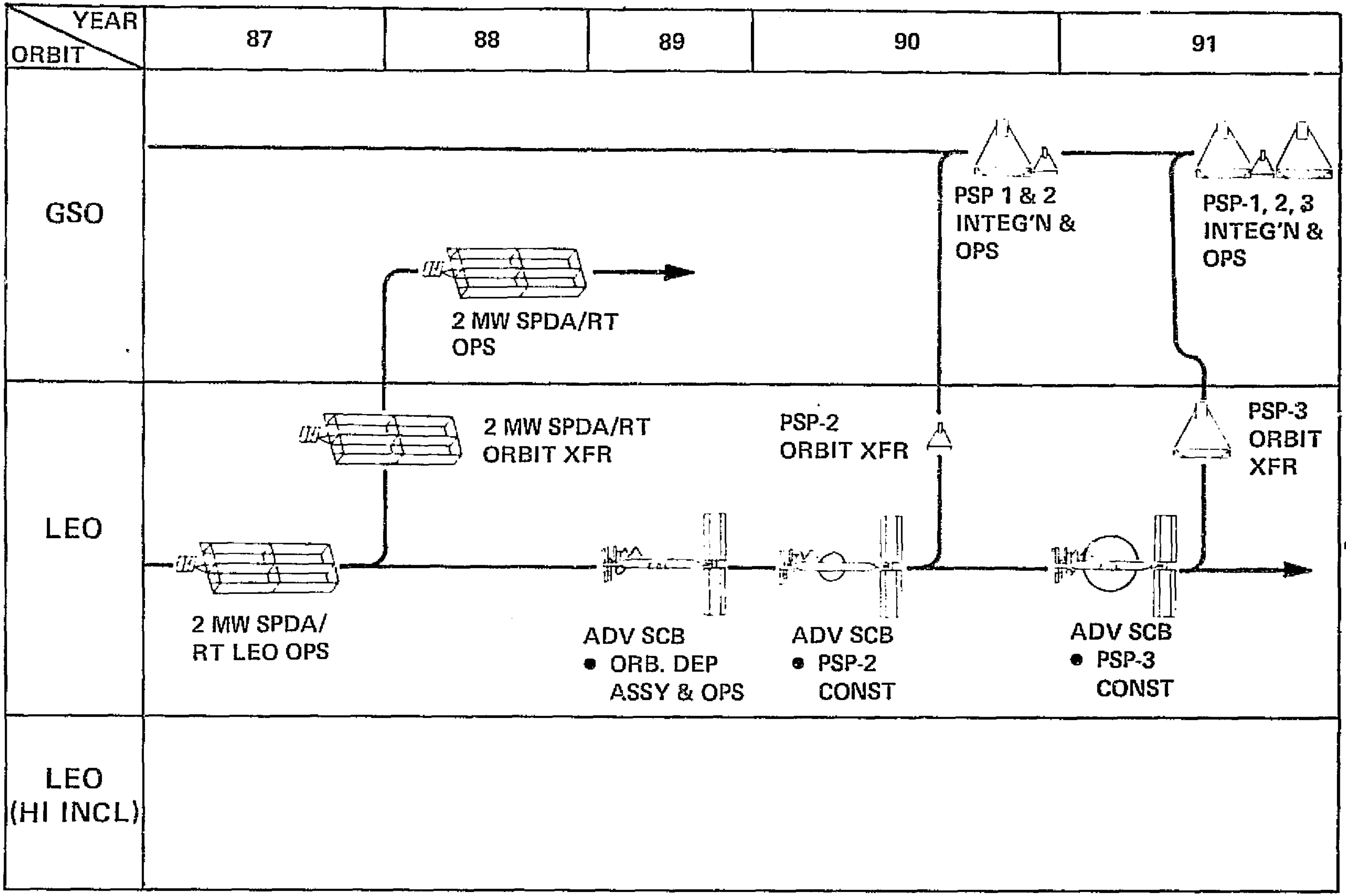
F-382

This chart continues the definition of options 1A, 1B and 3 from the previous chart through the year 1991. It is during this time frame that the Orbital Depot (ORB DEP) becomes operational and supports the Orbit Transfer Vehicle (OTV) which becomes the main carrier for transporting mission hardware between orbits.

The detached 2mw SPDA/RT remains in LEO throughout 1987 and is subsequently orbited into GSO by an Interim Upper Stage/Solar Electric Propulsion System (IUS/SEPS) combination; the GSO 2mw SPDA/RT becomes operational during 1988. In 1989, the LEO advanced SCB assembles, checks out and places into service the ORB DEP. After the ORB DEP assembly is completed, the second Public Service Platform (PSP-2) is constructed by the LEO advanced SCB, detached and placed into GSO by an OTV. There PSP-2 is integrated with PSP-1 which was orbited into GSO in 1985. The combined GSO PSPs become operational in 1990. The third PSP is constructed, transported and integrated in an identical manner as the second PSP. The combined GSO PSPs, i.e. PSP-1, 2 and 3, become operational in 1991.

F-383T

PROGRAM OPTION 1A, 1B & 3 (SHEET 2 OF 2)



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F-383

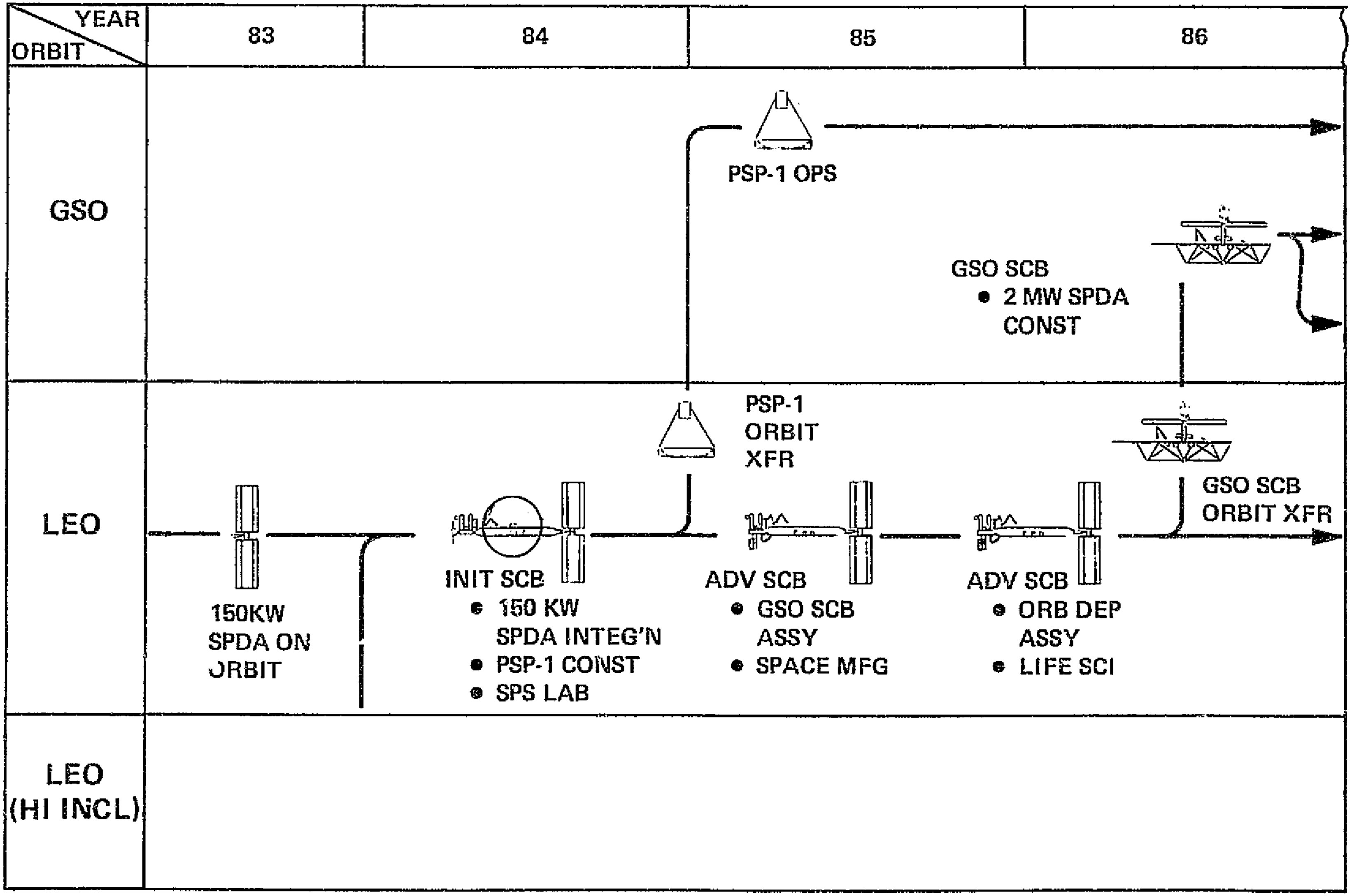
PROGRAM OPTION 2A

This chart defines the program Option 2A for the time frame from 1984 to mid-1986. The subsequent chart continues the definition through the year 1991. The one activity which distinguishes this option from all other options is the construction of large structures, e.g., the 2mw SPDA/RT, in geostationary orbit.

The early stages of this option are similar to option 1A. In 1984, the Option 2A initial SCB is assembled in LEO from modules launched from the ground and integrated with a 150kw SPDA left in orbit from a prior development program. The first PSP is then constructed with the assembled SCB, detached and orbited into a geostationary orbit where PSP-1 becomes operational during the first quarter of 1985. While the PSP-1 is being constructed, the SPS lab becomes operational. At this time, option 2A departs from the option 1A scenario. The initial SCB is enlarged to an advance SCB configuration in 1985 and the Space Manufacturing activity aboard the advance SCB becomes operational. The GSO SCB is assembled and left in LEO while the advance SCB assembles, checks out and places into service the ORB DEP. The OTV, serviced by the ORB DEP, then transports the GSO SCB to a geostationary orbit where construction of the 2mw SPDA/RT takes place during the early part of 1986. While the ORB DEP is being assembled, the LIFE SCI activity aboard the LEO advance SCB becomes operational.

F-385T

PROGRAM OPTION 2A (SHEET 1 OF 2)



GRUMMAN

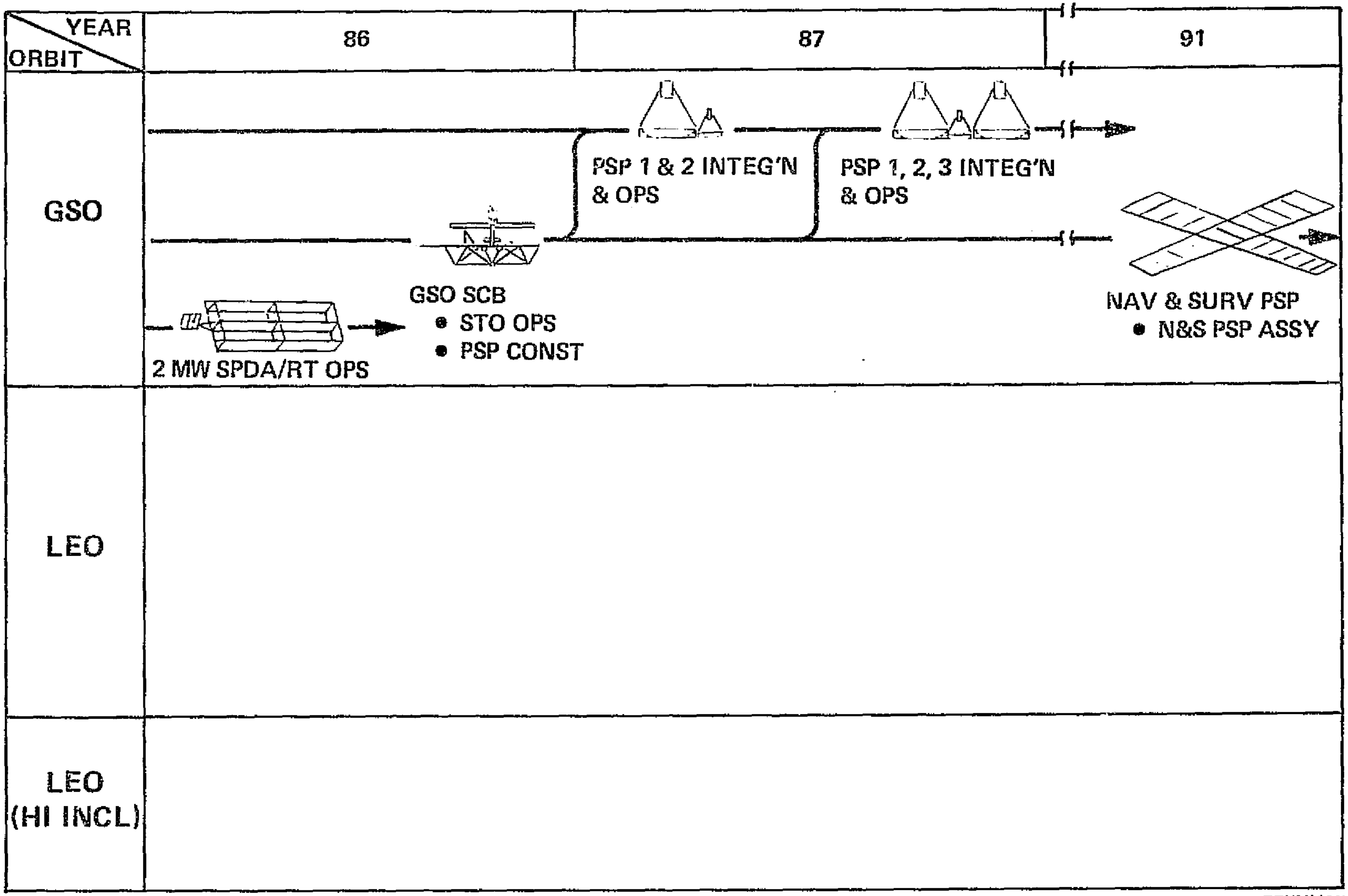
PROGRAM OPTION 2A (CONT)

This chart continues the definition of the Option 2A from the previous chart through the year 1991. Option 2A differs from Option 1A in the construction of large structures, such as the Public Service Platforms, in geostationary orbit.

It is seen from the previous chart that the GSO SCB constructed the 2mw SPDA/RT in early 1986. After construction and checkout, the 2mw SPDA/RT is detached from the SCB and is placed in service in mid-1986. It is at this time the STO lab aboard the GSO SCB becomes operational. The second Public Service Platform is constructed by the GSO SCB, detached from the base and integrated with PSP-1 which was orbited from LEO into geostationary orbit in 1985. The combined GSO PSPs are pressed into service in early 1987. The third PSP is constructed, detached and integrated in an identical manner as the second PSP. The combined GSO PSP's, i.e. PSP-1, 2 and 3, are pressed into service during the latter part of 1987. The last activity the GSO SCB performs during this time frame is construction of the Navigation and Surveillance Public Service Platform (N&S PSP).

F-386T

PROGRAM OPTION 2A (SHEET 2 OF 2)



GRUMMAN

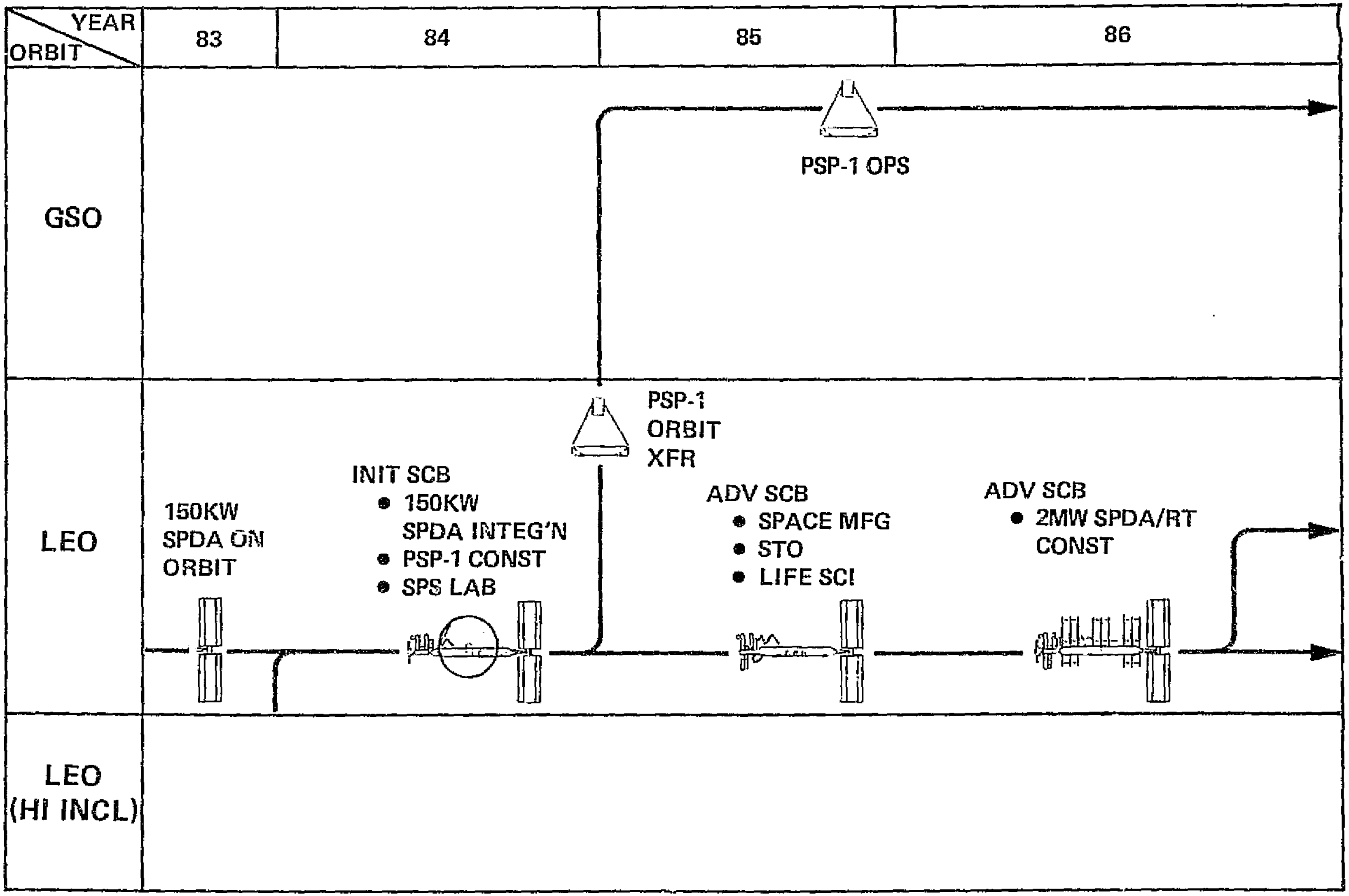
PROGRAM OPTION 2B

This chart defines the program Option 2B for the time frame from 1984 to mid-1986. The subsequent two charts continue the definition through the year 1991. The time-phased activities defined for Option 2B in this chart are identical to Option 1A. The differences between options begin in mid-1986.

In 1984, the Option 2B initial SCB is assembled in LEO from modules launched from the ground and integrated with a 150kw SPDA left in orbit from a prior development program. The first PSP is then constructed with the assembled SCB, detached and orbited into a geostationary orbit where it becomes operational during the first quarter of 1985. While the PSP-1 is being constructed, the SPS lab aboard the initial SCB becomes operational. Early in 1985, the initial SCB is enlarged to an advance SCB configuration and the Space Manufacturing, Solar Terrestrial Observatory (STO) and Life Science (LIFE SCI) activities aboard the LEO advance SCB become operational. The 2mw SPDA/RT is constructed by the advance SCB early in 1986.

F-387T

PROGRAM OPTION 2B (SHEET 1 OF 3)



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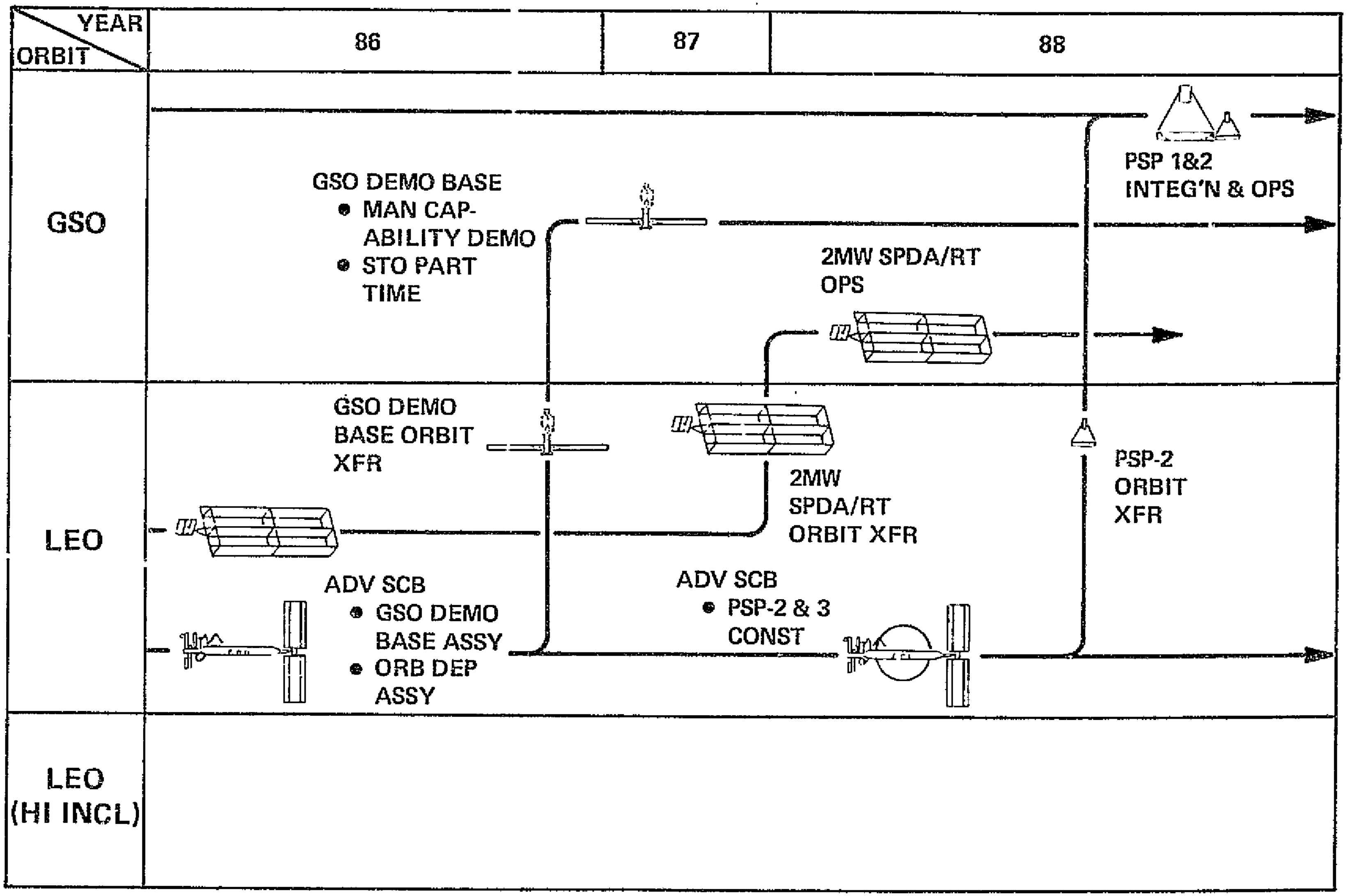
F-387

PROGRAM OPTION 2B (CONT)

This chart continues the definition of the Option 2B from the previous chart through the year 1988. The activity which distinguishes this option from other options is the placement of a GSO Demonstration Base (GSO DEMO BASE) into a geostationary orbit from LEO. This base allows frequent GSO sortie flights in which the crew performs part-time STO experiments and demonstrates man's ability to perform tasks in a geostationary orbit. This base is the forerunner of a Space Operations Base (SPACE OPS BASE) which is described in the subsequent chart.

It is seen from the previous chart that the LEO advance SCB constructed the 2mw SPDA/RT in early 1986. After construction and checkout, the 2mw SPDA/RT is detached from the SCB and is placed in service in early 1986 through 1987. It is during this time frame that the LEO advance SCB assembles the GSO DEMO BASE and the ORB DEP. The OTV, serviced by the ORB DEP, then transports the GSO DEMO BASE to a geostationary orbit. The GSO DEMO BASE contains a partial complement of STO equipment and the necessary equipment for man to demonstrate his ability to perform geostationary activities. In the early part of 1988, the OTV transports the 2mw SPDA/RT from LEO into a geostationary orbit. After the ORB DEP assembly is completed and in service, the second PSP is constructed by the LEO advance SCB, detached and placed into GSO by the OTV in the second quarter of 1988. There PSP-2 is integrated with PSP-1 which was orbited into GSO in 1985. The combined GSO PSPs become operational in 1988.

PROGRAM OPTION 2B (SHEET 2 OF 3)



GRUMMAN

F-388

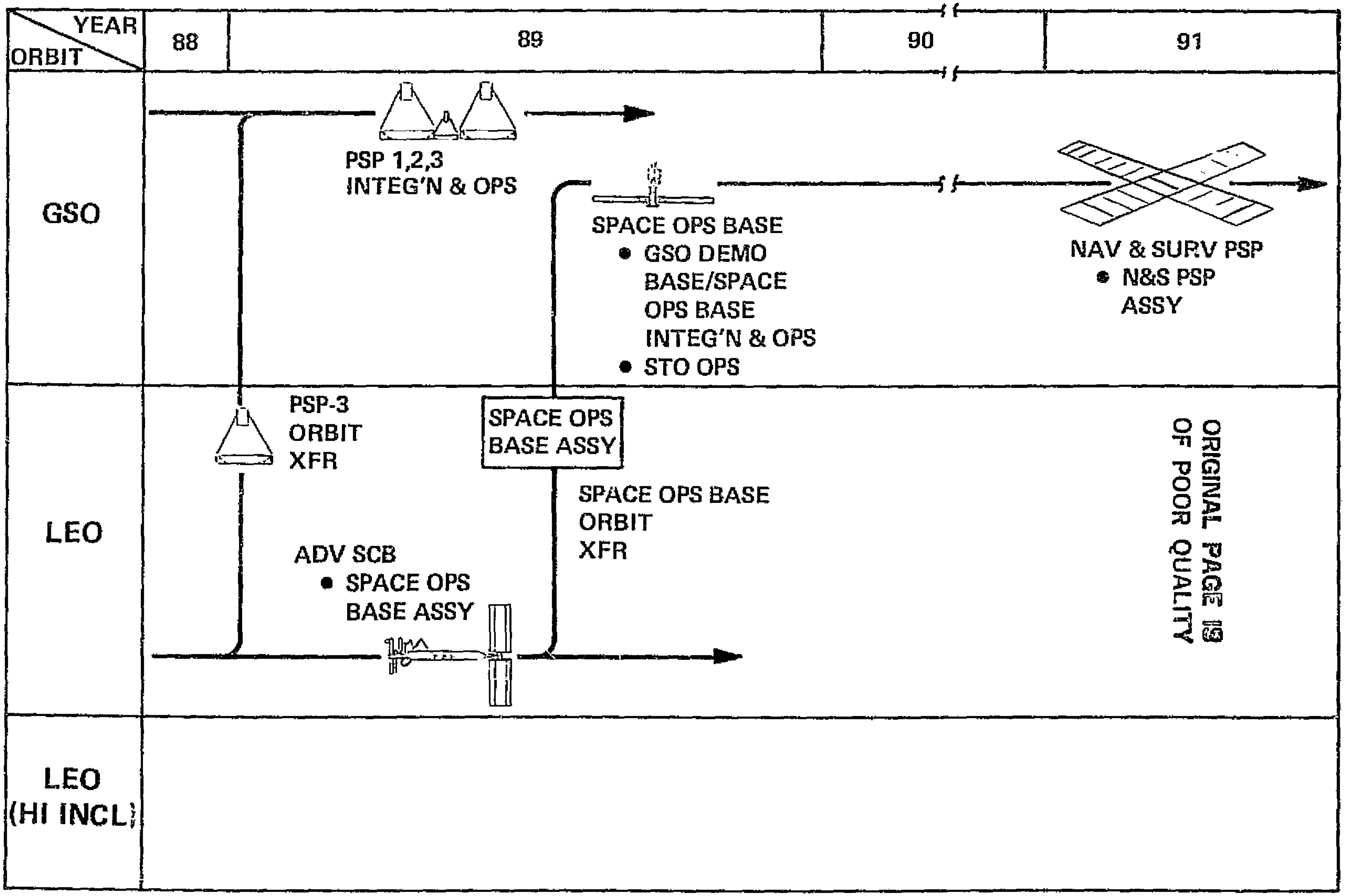
PROGRAM OPTION 2B (CONT)

This continues the definition of the Option 2B from the previous chart through the year 1991. The activity which distinguishes this option from other options is the growth of the GSO DEMO BASE into a Space Operations Base (SPACE OPS BASE). The SPACE OPS BASE houses a permanant crew, a full complement of STO experiments and the necessary equipment to assemble the N&S PSP.

The previous chart shows that the second PSP was constructed by the LEO advance SCB, detached, transported into a geostationary orbit by the OTV and integrated with the PSP-1. The combined GSO PSP's become operational in 1988. Early in 1989, the third PSP is constructed, detached, transported and integrated in the same manner as the second PSP. The combined GSO PSP's, i.e., PSP-1, 2 and 3, are pressed into service during early 1989. The SPACE OPS BASE is assembled by the LEO advance SCB and is transported to a geostationary orbit by the OTV. There the SPACE OPS BASE is integrated with the GSO DEMO BASE. The SPACE OPS BASE, with its permanent crew and full complement of STO experiments, becomes operational in 1989. The last activity the SPACE OPS BASE performs during this time frame is construction of the N&S PSP. This occurs in 1991.

F-389T

PROGRAM OPTION 2B (SHEET 3 OF 3)



GRUMMAN

F-389

INTEGRATED SCB REQUIREMENTS IN ORBIT
BY QUARTER YEAR
OPTION 1B-LEO

The graphs on this chart summarize the integrated SCB requirements for Option 2B for the time period between 1984 through 1991. The requirements are used to determine transportation requirements, design modifications and program costs. Similar requirements data were developed for all program options.

Manpower requirements (NO. OF CREW) peak at 10 men in 1990. The average manpower requirements for the initial SCB is five men; for the advance SCB, it is eight men. An average of five men is required for the FLT OPS & OTHER category. Of the five men, three are required to man the SPS, STO and LIFE SCI labs. The PSP and 2mw SPDA/RT construction and C/O tasks never require more than two men. The ramps which appear on the Space Manufacturing curve are a function of when the biological, solidification and crystal branch modules come on line. Two men who are borrowed from the FLT OPS & OTHER category are required to assemble the ORB DEP in 1989.

Electrical power requirements peak at approximately 70 kw in 1990. The peak electrical power requirements for the initial SCB is approximately 35 kw of which 11 kw is required to construct the 150 kw SPDA. The average electrical power for the initial base runs about 20 kw. With respect to the advance SCB, the average electrical power runs about 55 kw up to 1989; after 1989 the average electrical power runs about 65 kw. The jump in electrical power average is attributed to increased Space Manufacturing activity. The PSP construction during 1984, 1990 and 1991 require approximately 7 kw. The 150 kw SPDA and the 2mw SPDA/RT require about 11 kw during SCB BUILD-UP & C/O and CONST & C/O activities in 1984 and 1986 respectively. The SPACE MFG ramps are a function of increased activities.

The major drivers contributing to the peaks appearing on the MASS and VOLUME curves and to a lesser extent on the NO. OF CREW and ELECTRIC POWER are as follows:

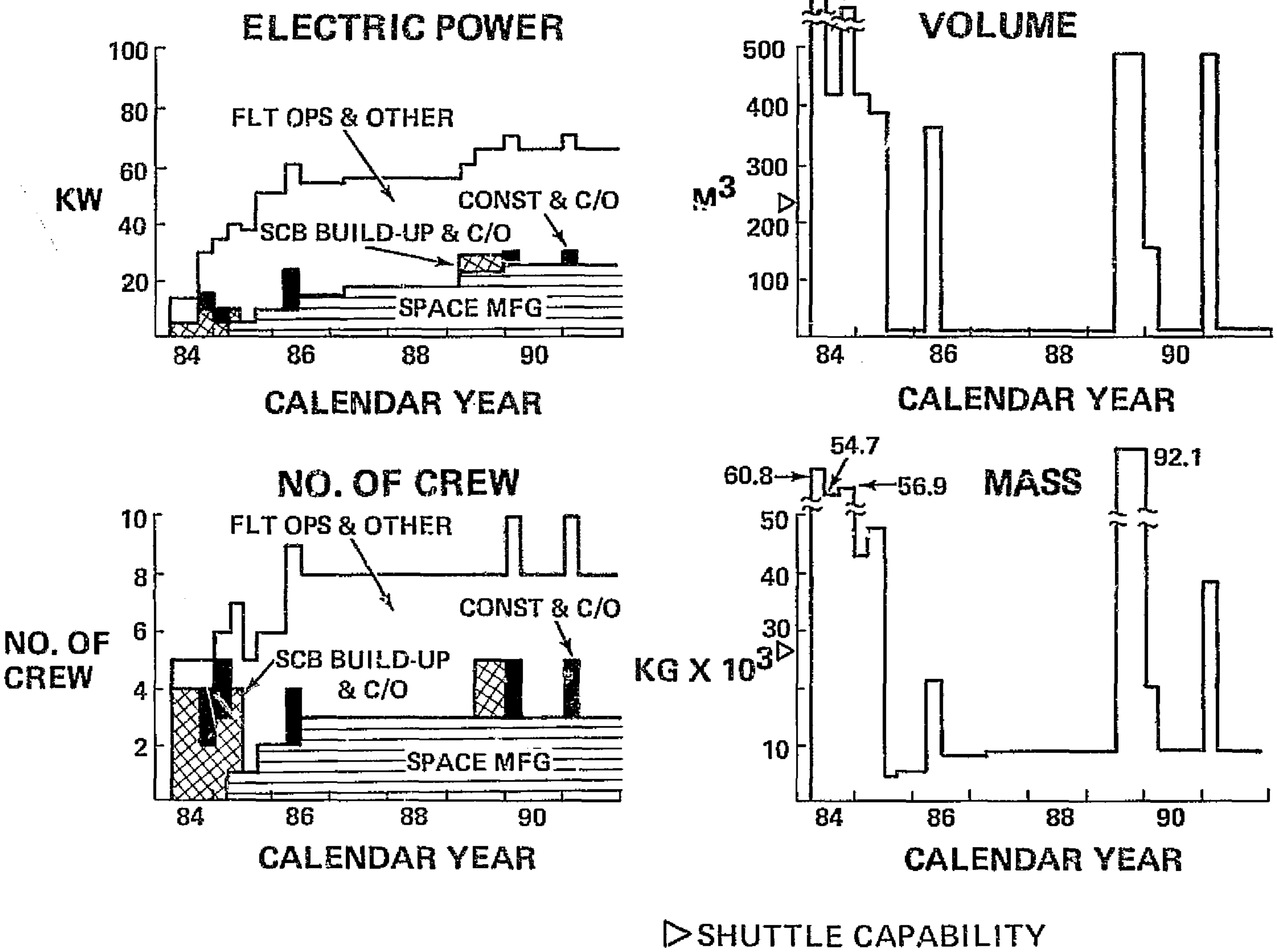
- 1984 – LEO initial SCB build-up, 150 kw SPDA and PSP-1 construction
- 1985 – LEO advance SCB build-up
- 1986 – 2mw SPDA/RT construction
- 1989 – ORB DEP build-up
- 1990 – PSP-2 construction
- 1991 – PSP-1 construction

Approximately 8000 kilograms of mass and 8 m^3 of volume are required per quarter from 1984 through 1991 for crew rotation, expendables, RCS propellant, space manufacturing materials and spares.

F-327T

INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 1B – LEO



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F-327

SUMMARY OF INTEGRATED SCB REQUIREMENTS 1984 THRU 1991

This chart summarizes the integrated SCB requirements for each option from 1984 through 1991.

The maximum number of crew for the LEO initial SCB for all options is five men. The maximum number of men required for the LEO advance SCB for each option is a function of when or in what orbit an activity occurs. Consequently, option 2A shows a maximum crew requirement of two less than for options 1 and 3 because the PSP-2, PSP-3 and 2 mw SPDA/RT construction are done in GSO and not in LEO. The one-man difference in the LEO advance SCB between options 2B and 3 is attributed to the Space Operations Base assembly and scheduling.

The difference in masses between option 1A and 1B is attributed to the option 1B 150kw SPDA construction. The low mass in LEO orbit for option 2A (and the corresponding high mass in GSO) is the result of construction activity in GSO. The GSO Demonstration Base in option 2B accounts for the relatively high GSO mass.

The electrical power requirement for the option 2A LEO advance SCB is lower than that for the other options because of lesser construction in LEO.

F394T

SUMMARY OF INTEGRATED SCB REQUIREMENTS – 1984 THRU 1991

REQUIREMENT – ORBIT	OPTION 1A	1B	2A	2B	3
MAX NO. OF CREW					
LEO (INIT SCB/ADV SCB)	5/10	5/10	5/8	5/11	5/10
GEO (VIA LEO)	–	–	3 ('86)	3('90)	–
LEO HI-INCL	–	–	–	–	3
TOTAL MASS (KG X 10^3)					
LEO (DRY)	462	488	380	450	456
GSO (VIA LEO)	78	78	250	143	78
LEO HI-INCL	–	–	–	–	134
TOTAL OTV PROPELLANT	455	455	1826	999	455
TOTAL VOLUME (M^3)					
LEO	4500	4600	5200	5000	4000
LEO HI-INCL					1700
MAX CONT ELECT. PWR (KW)					
LEO (INIT SCB/ADV SCB)	25/70	25/70	25/60	25/70	25/70
GSO	–	–	33	28	–
LEO HI-INCL	–	–	–	–	25

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F-394

INITIAL SPACE CONSTRUCTION BASE LEO, 28 1/2° INCLINATION – OPTION 1 A/B, 2A/B & 3

With these program options, the Initial SCB is the first facility in a series of construction bases with developing capabilities. Buildup of the initial base is described elsewhere in this section. Flight and nadir directions shown on the figure provide minimum drag and utilize gravity gradient to minimize control penalties.

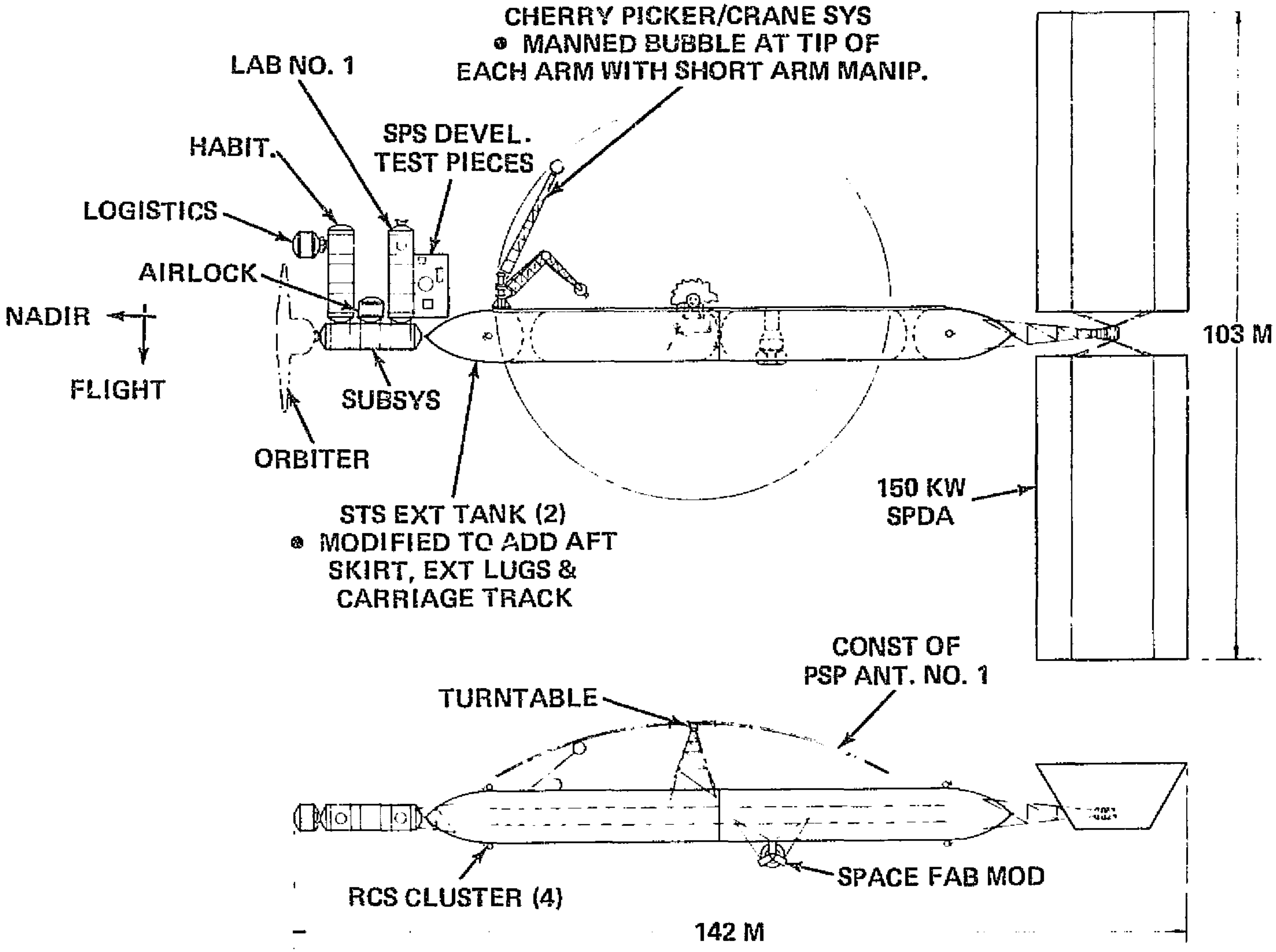
Separate habitation and subsystems modules house the crew and cater for station operations. These two facilities could be combined into one module for this Initial SCB with its crew of five but development of the SCB through to the Orbital Depot calls for more crew and, therefore, more habitation. Hence, separate modules are provided. A logistics module with supplies for 90 days is attached to the habitation module within reach of the shuttle manipulator for exchange of empty and full modules. The external airlock permits EVA. Primary docking for the shuttle is provided on the subsystems module. Emergency docking is on Lab No. 1. This laboratory caters for SPS development and construction testing, inspecting, monitoring, etc. A platform is provided external to the lab for SPS test pieces to check environmental effects, etc. This platform is within reach of the crane manipulators. The 150 kw solar array is an SPDA previously built in orbit from shuttle sortie missions and available for attaching to the SCB to provide power.

Considering the construction facility, this SCB builds the PSP Antenna No. 1 whose component parts are brought to orbit in the shuttle and assembled by this facility. A trussed tower mounts a turntable which serves as the assembly base from which the antenna is built radially from its center. The components are handled by the crane manipulator system which has two articulated arms mounted on a carriage which runs along the track attached to the "STS External Tanks" spine. At the tip of each articulated arm is a pressurized bubble housing a man in shirtsleeves operating short arm manipulators. The manipulator docks the bubble to the laboratory for the operator to 'go home'. A space fabrication module is there to provide four 1 m beams which form struts mounting the feed horn to the antenna. With program Option 1B, the construction facility also builds the 150 kw solar array since, in this option, it has not been built previously as an SPDA by shuttle sortie flights. The building of this array is described elsewhere in the 'Progressive Development' option.

C304T

INITIAL SPACE CONSTRUCTION BASE

LEO, 28½ DEG INCL - OPTION 1A/B, 2A/B & 3



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GRUMMAN

G-304

ADVANCED SPACE CONSTRUCTION BASE LEO, 28 1/2° INCLINATION – OPTION 1 A/B, 2B & 3

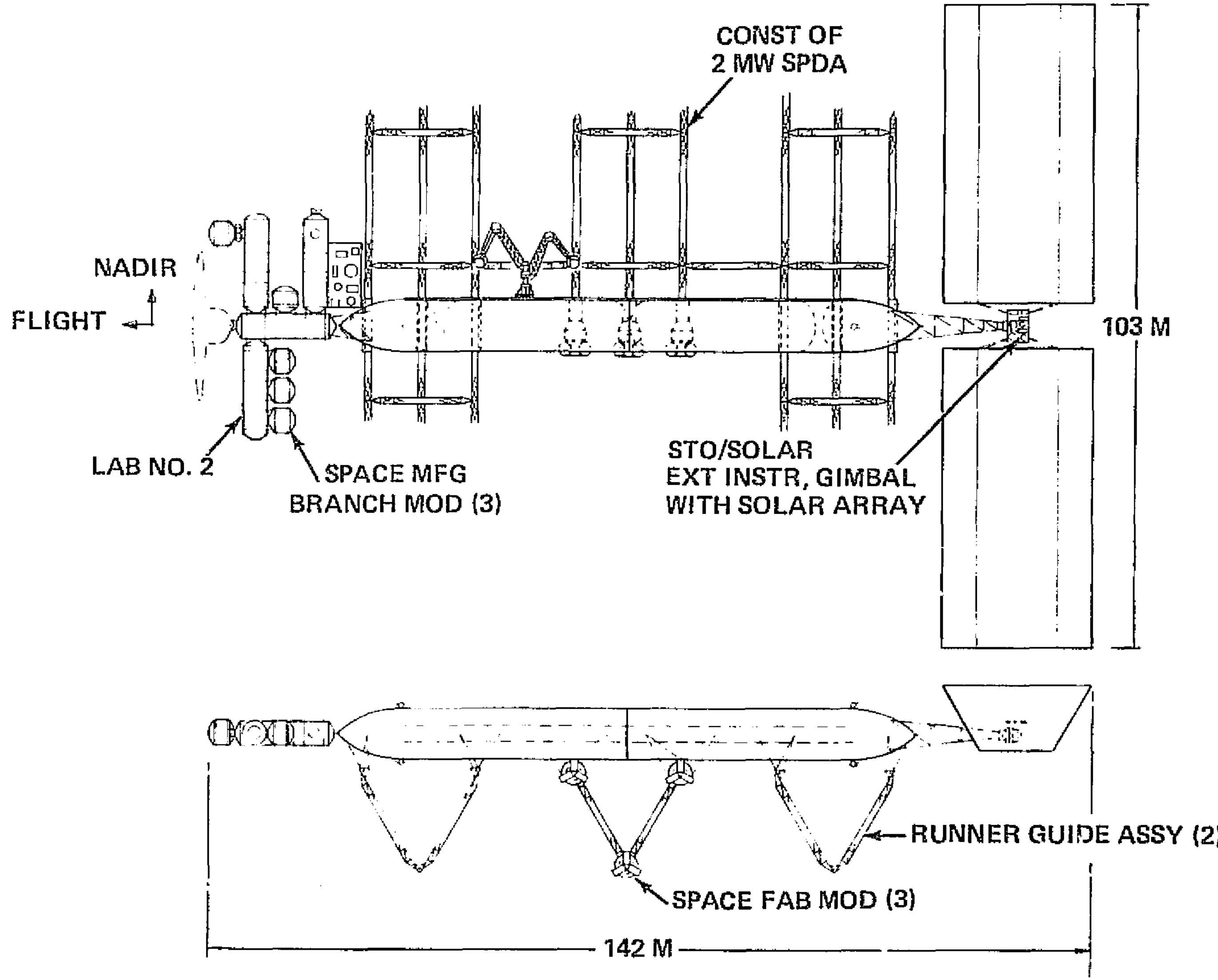
The Advanced SCB is a development of the Initial SCB. To augment the construction capability, two space fabrication modules are added to make a total of three modules in a triangular formation, ready to send out 1 m beams in their correct relationship for manufacture of the 2 mw SPDA. Two runner guide assemblies are added outboard of the space fabarication modules as part of the SPDA building fixture. Construction of the 2 mw SPDA is described elsewhere. Later in the program additional construction/assembly fixtures will be provided for building the PSP antennas No. 2 and No. 3.

Additional non-construction facilities are, augmented habitation and subsystems for four more crew, an additional laboratory and STO facility. The additional crew men are housed in the habitation module, which can readily accommodate them. The laboratory caters for Manufacturing Development, Life Sciences and STO. The manufacturing development facility includes three small modules external to the main laboratory and are described in the section dealing with space manufacture. Life Sciences experiments are also carried out in this lab. The only STO experiments performed on this base are solar observations. Their associated electronics are housed in the lab but the observation instruments are external and are mounted on a platform between the two wings of the 150 kw SPDA. They gimbal with the array to track the sun. These instruments are within reach of the crane for servicing or film exchange.

The flight and nadir directions shown on the figure minimize drag and gravity gradient penalties when the 2 mw SPDA has grown during its construction. Before and after the 2 mw SPDA constrution, the arrows indicating nadir and flight are reversed to give minimum drag and gravity gradient penalties for that configuration.

G303

ADVANCED SPACE CONSTRUCTION BASE
LEO, 28½ DEG INCL 1A/B & 2B



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G-303

USE OF THE STS EXT TANK IN ORBIT OPTIONS

Use of the STS external tank as part of the SCB is an attractive option. The chart shows possible tank modifications whose complexity increases with use.

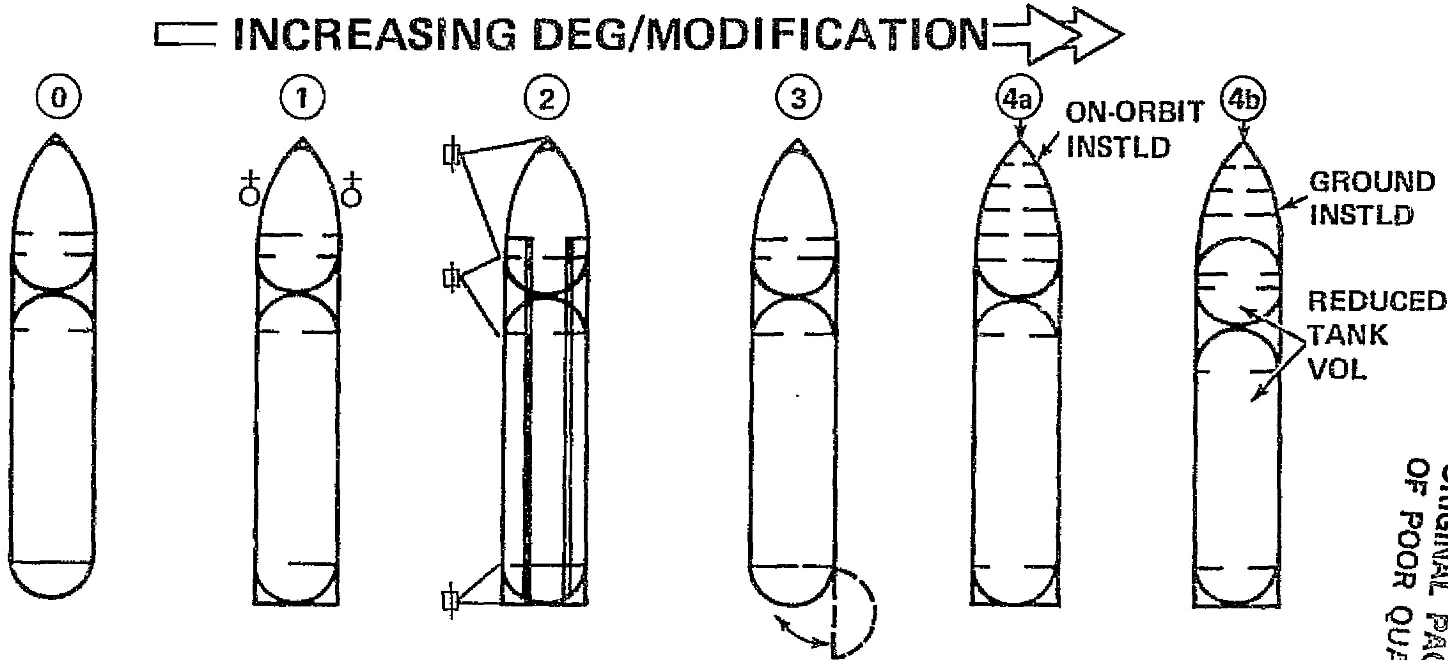
An unmodified tank can be used in orbit as a source of raw material for manufacture or as mass driver reaction. A tank with some attachment points added is useful as a mass to govern inertia characteristics of an SCB or as a stiff spine. The current LEO SCB uses two tanks joined together at their aft ends to provide a long structural spine and includes external rails to carry a transportation carriage. The above modifications are external to the tank and are effected on the ground.

Internal modifications to the tank range from an end dome opening as a swing door to provide shelter, to internal habitation and installation of subsystems hardware inside the tank, either in orbit or on the ground.

G342T

USE OF THE STS EXT TANK IN ORBIT

OPTIONS



MODIFICATION:				
	JOINT ADAPTER RCS/FLT CONT	EXTNL RAILS JIG ATTACHMT POINTS	SWING DOOR	HABITATION SUBSYSTEMS
USE:				
SOURCE OF RAW MATERIAL FOR: • RECYCLED ALUM • MASS DRIVER REACTION	HIGH INERTIA SPACE SPINE	CONST BASE SPINE	SHELTER	LIVING QUARTERS

GRUMMAN

LEO - SCB - CIRCULATION, PASSAGES AND OPENING SIZES

The arrangement shown is baseline for this reporting period. The planar architectural configuration utilizes the subsystem module as the central spine for initial SCB construction. The subsystem, habitat and lab modules are all the same size (4.06 m dia X 15.75 m long). Each module has an identical core size, and configuration, with five branch cylinders. A branch dia of 1.65 m is used to mechanically attach additional modules. With allowance for bolted connections, seals,electrical wiring and ducting interfaces a 1.0 m X 1.25 m opening between modules is achieved. The core module has either a branch type attachment, international docking ring, or dome end affixed at its ends.

This configuration produces a standardized module that can be utilized for all types of internal functions.

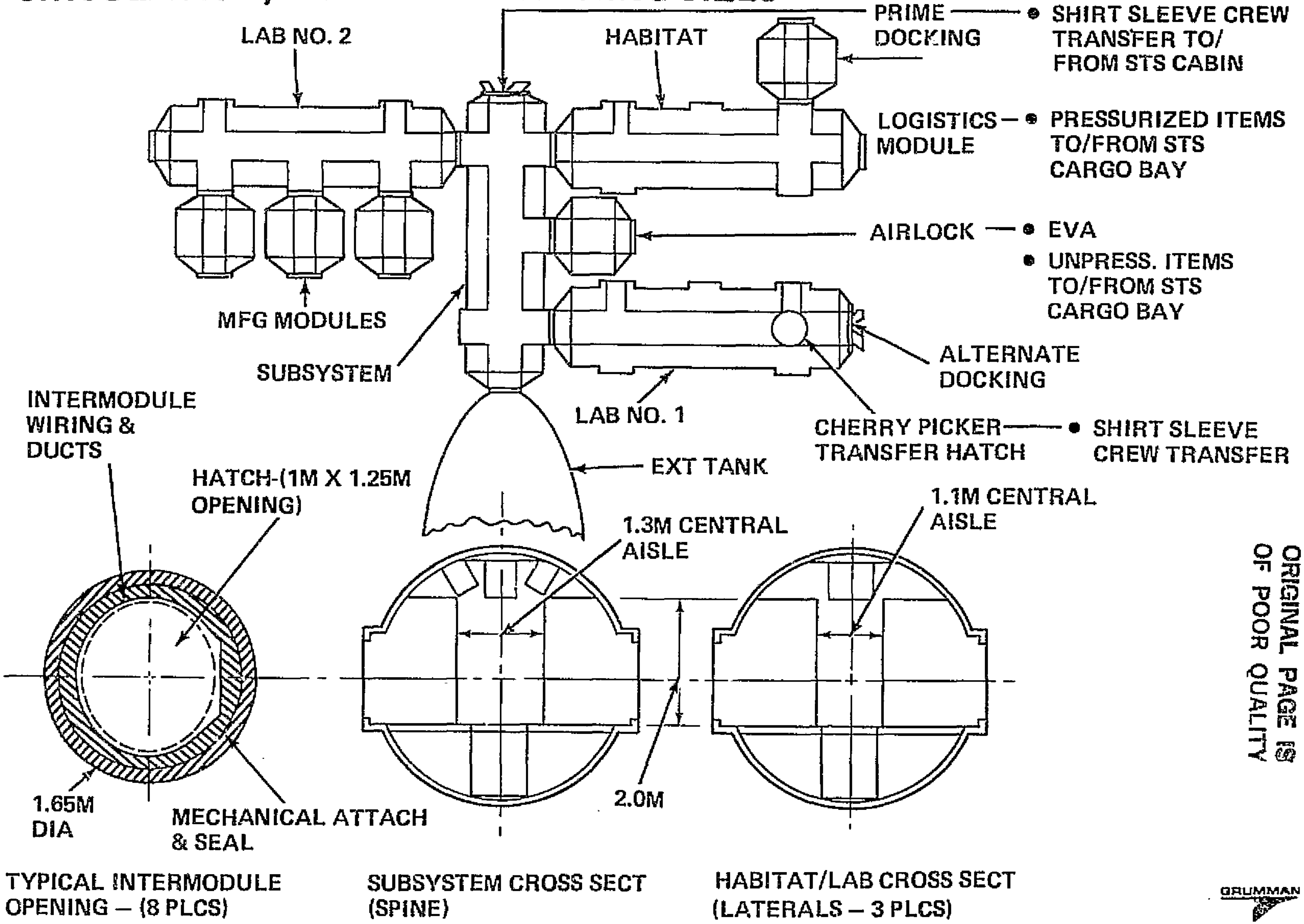
The cross sections of the HAB, SUB system and LAB's are very similar, the main difference being the aisle width. Commonality of modules is a design goal for minimizing development costs.

The airlock and logistic modules are shortened versions of the standard modules and contain many design commonality features of the larger units.

The circulation through the SCB utilizes a 1.1 m aisle in this wing modules and a 1.3 m aisle in the core module. A hatch located at each branch permits isolation of a module if required by crew operation or emergency conditions.

G-398T

LEO SCB
CIRCULATION, PASSAGES & OPENING SIZES



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G-398

HABITATION MODULE

This module attached to the subsystem module can support 11 men for 90 days. A commander's quarters/office plus nine crew quarters are provided. For the short time span of the lengthy mission when an eleventh man is required, the EMU compartment is converted to a crews quarter. The five EMU'S are relocated to the subsystem module on a temporary basis. When the eleventh man departs this volume is reconfigured as an EMU stowage facility.

A waste management compartment and personal hygiene compartment, with shower, are located at the end of the module near the subsystem module, thus providing maximum access to all areas of the SCB. The galley/wardroom located at the other end is at the farthest extremity of the central spine, thus providing an area of minimum activity. A hexagon shaped table with plug in food trays provide eating facilities for six crew men at one sitting. Providing for all 11 men at one sitting would be volume consuming. The galley/freezer/chiller are contemplated to be skylab hardware.

The exercise center is located in the dome end portion of the module. Crew members can utilize the facilities without impairing movement of other crew members on duty.

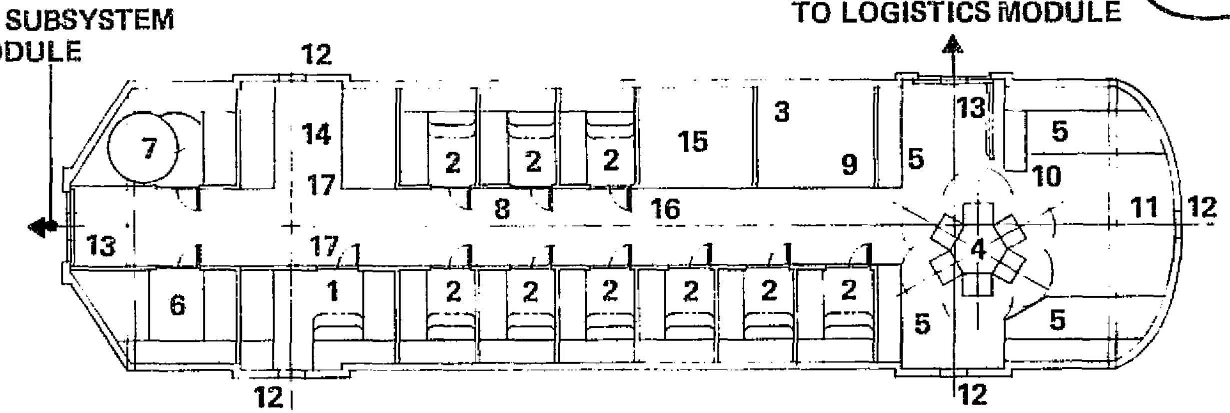
A logistic module (L/M) attached to the branch near the galley minimizes traffic when transferring food, waste and personal equipment between the modules. The L/M is mechanically fastened to the branch, thus providing a 1 m X 1.25 m opening rather than an .82 m dia produced with the international docking ring.

ECLS, electronics, navigation and guidance, EPS, etc. equipment is located in a floor to ceiling compartment .8 M long. Equipment is stowed in full length overhead lockers. A central aisle below the floor provides access to approximately 25 M^3 of additional equipment installation.

Four 50-cm dia windows provide visibility to the outside environment.

HABITATION MODULE

• HABITATION FOR 11 MEN



CREW LIVING	CREW SUPPORT	MISSION SUPPORT
1. CMDRS QTRS/OFFICE	9. EMU (5)	14. CONTROLS & DISPLAYS
2. CREW QUARTERS (9)	10. REST & RECREATION EQUIP	15. ELECTRONICS, ECS, ETC.
3. CREW QUARTER(1)-WHEN RQ'D	11. EXERCISE CENTER	16. STOWAGE (CEILING)
4. DINING AREA	12. 50 CM WINDOW (4)	17. SUBSYSTEMS (BELOW FLOOR)
5. GALLEY/FREEZER/CHILLER	13. HATCH – 1.0 x 1.25M OPEN. (2)	
6. WASTE MANAGEMENT		
7. PERSONAL HYGIENE		
8. AISLES/PASSAGEWAYS – 1.1M		

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GRUMMAN

"FLEXIBLE FLIER" CONTROL REQUIREMENTS

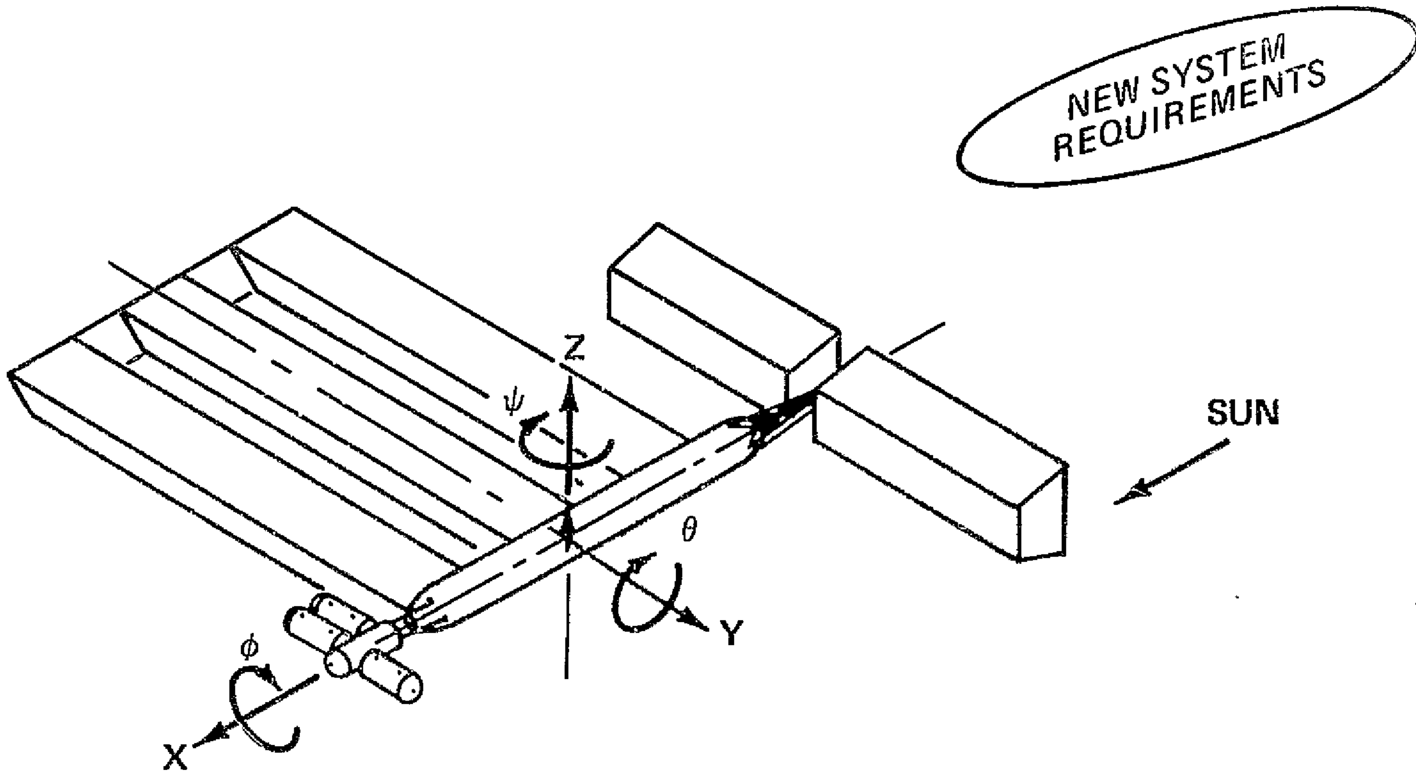
New flight control requirements associated with Space Construction Base operations relate to:

- Stabilization of the Space Construction Base (SCB) as very large elastic structures are fabricated
- Very large changes in vehicle configuration (SCB, Orb Depot, STO and Earth Resources Lab, etc) and corresponding inertia properties.

In addition, in order to conserve RCS propellant expenditure in orbit during periods when large limit cycle motions are acceptable from a mission standpoint, a passive means of stabilization is needed. Use of gravity gradient and aero drag are candidates for this requirement.

K404T

"FLEXIBLE FLIER" CONTROL REQUIREMENTS



- STABILIZATION OF LARGE ELASTIC STRUCTURE
- STABILIZATION AND CONTROL OVER VERY WIDE RANGE OF CONSTRUCTION BASE CONFIGURATIONS
- RCS PROPELLANT SAVINGS THROUGH USE OF GRAVITY GRADIENT AND AERO DRAG TORQUES FOR PASSIVE STABILIZATION
- PRECISION POINTING VIA ACTIVE CONTROL FOR DOCKING

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GRUMMAN

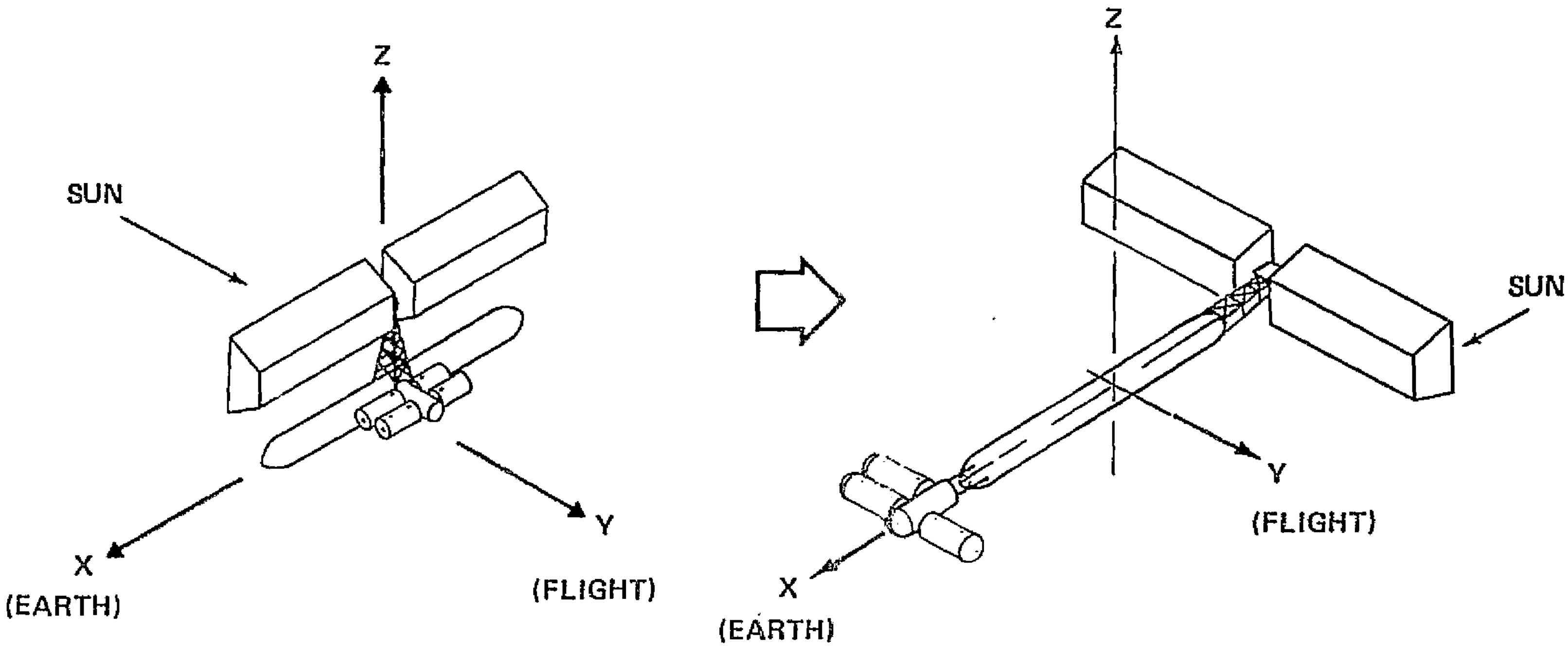
VEHICLE DESIGN MODS FOR IMPROVED FLIGHT CONTROL – SPACE CONSTRUCTION BASE

Two modifications were made to the 30 November, 1976 Space Construction Base configuration. The base solar array was relocated from atop the Z-axis post to an aft location on the base spine (X-axis). The modules for habitation, subsystems, etc. which were placed amidship previously are relocated to a forward position on the base spine (X-axis). Both of these modifications halved the X-axis moment of inertia and increased the Y- and Z-axes moments of inertia by a factor of 3.8. Taken together, these moment of inertia changes increase the difference between the Z- and X-axis inertias and between the Y- and X-axis inertias by a factor of 6.5. The net effect increased the gravity gradient stabilizing torque by a factor of about 5.2. This contributes materially to the concept of passive stabilization.

F-362T (K-313T)

VEHICLE DESIGN MODS FOR IMPROVED FLIGHT CONTROL
SPACE CONSTRUCTION BASE

NOV 30 CONFIG | PRESENT CONFIG



MOD

- MOMENT OF INERTIA DIFFERENCES

  $(I_Z - I_X)$ AND $I_Y - I_X)$ INCREASED

  BY FACTOR OF 6.5

EFFECT

- GRAVITY GRADIENT STAB TORQUE INCREASED BY FACTOR OF APPROX 5.2
- APPROX 500 LB OF RCS FUEL SAVED FOR 90 DAY MISSION

GRUMMAN

K-313 (F-362)

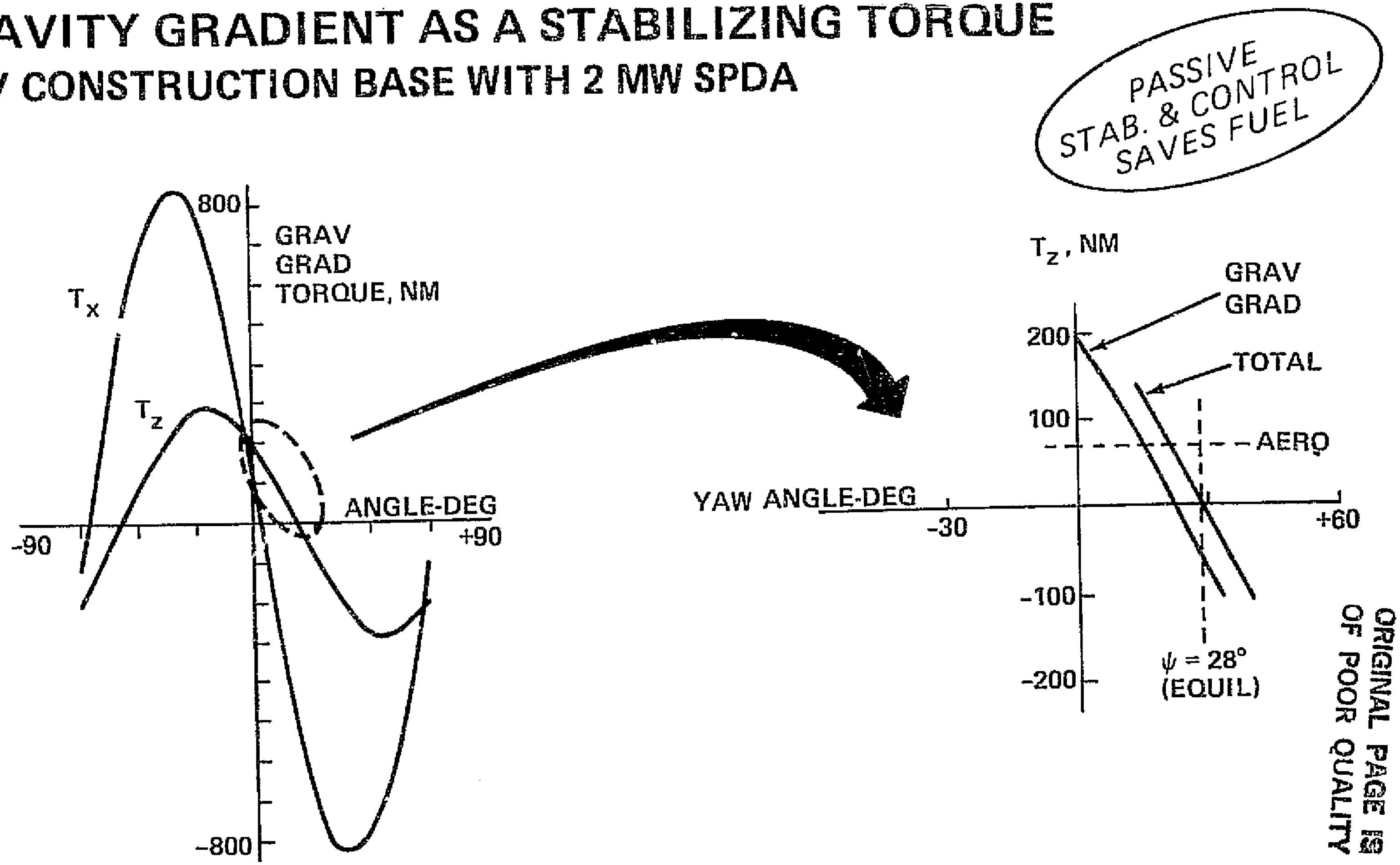
GRAVITY GRADIENT AS A STABILIZING TORQUE

On the left side, the results of a gravity gradient torque survey are presented for the Advance Construction Base configuration with the 2 mw Solar Power Development Article attached. X- and Z-axis torque profiles over a 180 deg angular range are shown to approximate sine functions. The angle at which each curve crosses the zero torque axis (near the zero angle point) corresponds to the misalignment between principal and vehicle geometric axes. This angular difference is attributable to the existence of cross products of inertia The local slope of both torque plots in the ± 30 deg range is both linear and negative. This indicates the gravity gradient provides a restoring torque which can contribute to passive stabilization.

On the right side, the section of the T_Z (due to gravity gradient) versus angle curve has been expanded in the angular range from 0 to 30 deg. Added to this plot is the aerodynamics torque which must be countered by the gravity gradient torque. As shown, at a yaw angle of 28 deg, these torques are equal in magnitude and opposite in sign. Thus, the vehicle will tend to maintain an equilibrium condition at this angle. The limit cycle oscillation about the equilibrium position will be suppressed in accordance with the damping that is supplied as part of the control loop.

F306T

GRAVITY GRADIENT AS A STABILIZING TORQUE
ADV CONSTRUCTION BASE WITH 2 MW SPDA



- GRAV GRAD PROVIDES RESTORING TORQUE THAT OFFSETS AERO AND OTHER DISTURBANCE TORQUES
- STABILIZATION OBTAINED WITHOUT EXPENDITURE OF RCS PROPELLANT

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F-306

SIMULATION RESULTS OF FLEX MODE STABILIZATION

Grumman has developed a combined rigid/flexible body dynamic model for the adaptive control technique. The model has been programmed for digital simulation. The dynamic properties of the Advanced Construction Base configuration with the 2 mw Solar Power Development Article attached were evaluated. Results are shown for roll motion about the X-axis with the first three bending modes included. Roll rate as a function of time is presented. Two effects may be noted. The oscillation having a period of about 60 sec corresponds to the 0.1 rad/sec first bending mode. The longer period oscillation (about 600 sec) represents the second mode (0.01 rad/sec). Both of these oscillations are damped indicating the ability of the control algorithm to stabilize the roll motion.

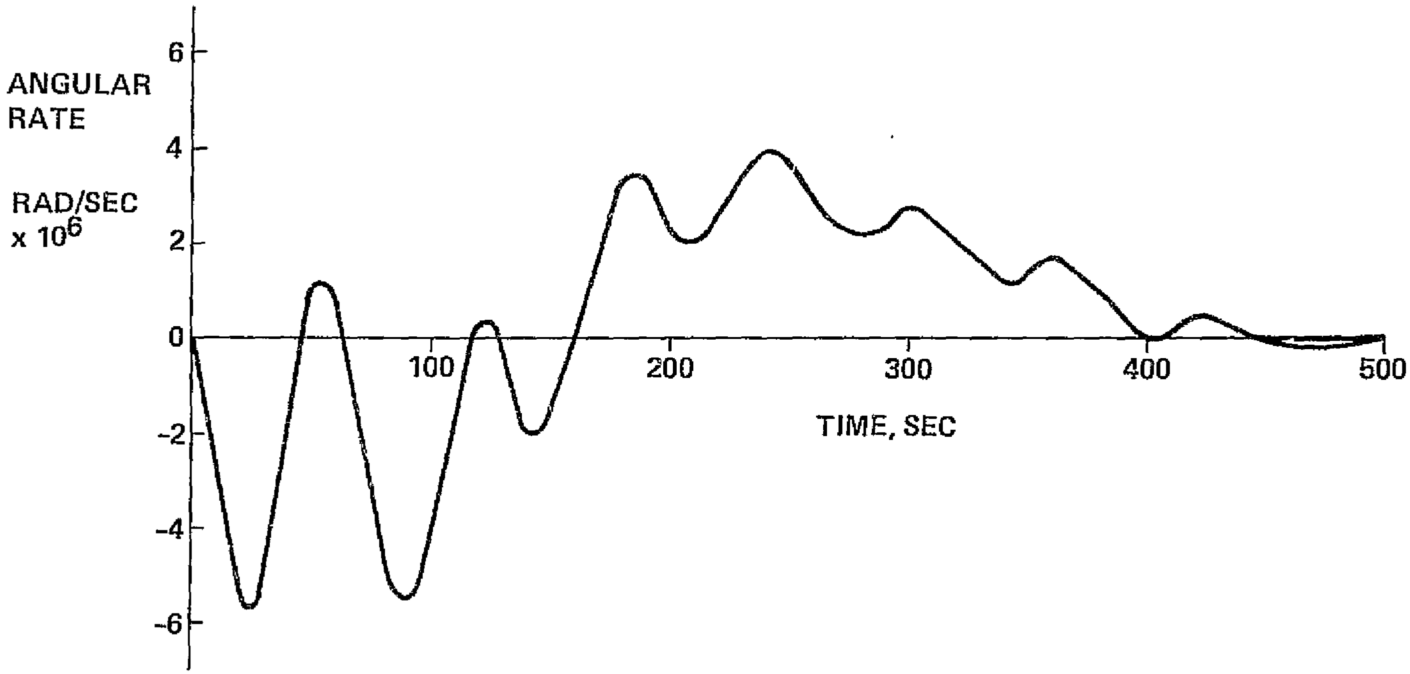
F375T

SIMULATION RESULTS OF FLEX MODE STABILIZATION

ASSUMPTIONS

- ADV CONST BASE WITH 2 MW SPDA
- X-AXIS MOTION ONLY ($I_{XX} = 4.5 \times 10^8$ KG-M^2)
- THREE BENDING MODES (0.1, 0.01 AND 0.001 RAD/SEC)
- NO STRUCTURAL DAMPING

MOTION WITH SUPPRESSED BENDING MODES



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GRUMMAN

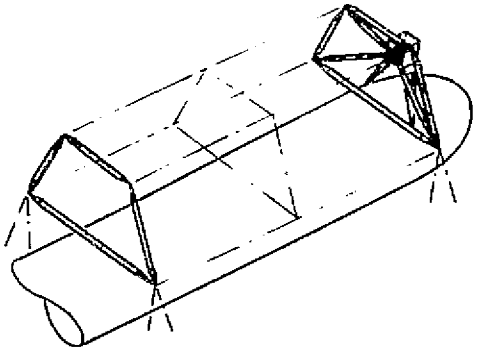
F-375

150 KW SPDA BUILDUP

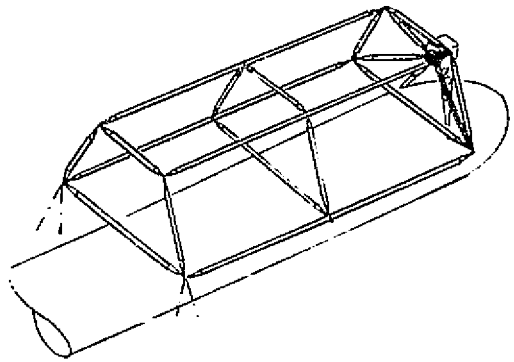
The 150 kw SPDA buildup is demonstrated as shown. It is representative of four typical steps in the sequential assembly procedure.

FOUR TYPICAL STEPS IN 150 KW SPDA ASSEMBLY

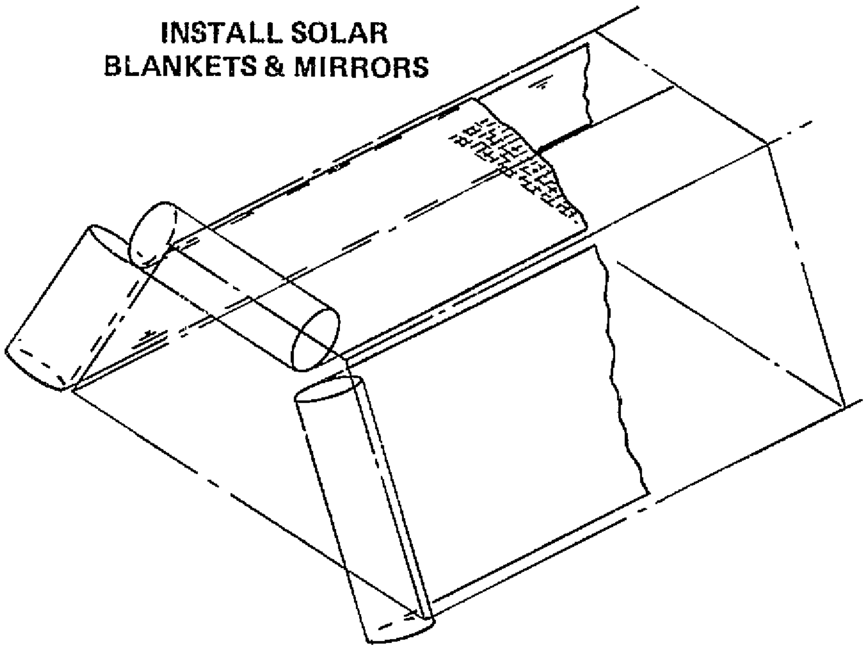
BUILD END CAPS



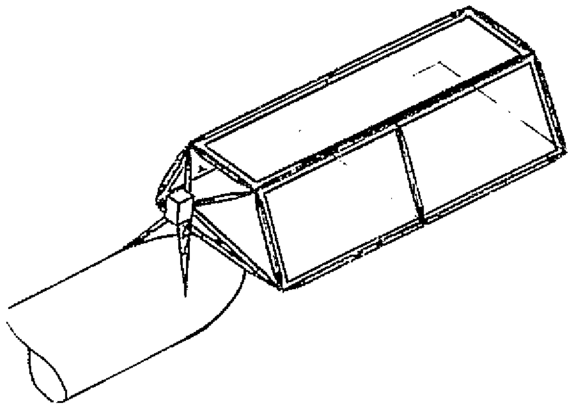
COMPLETE BEAM STRUCTURE



INSTALL SOLAR
BLANKETS & MIRRORS



ROTATE MAST AND READY
FOR 2ND BEAM



ALTERNATIVE DEVELOPMENT TACTICS FOR 150 KW SPDA

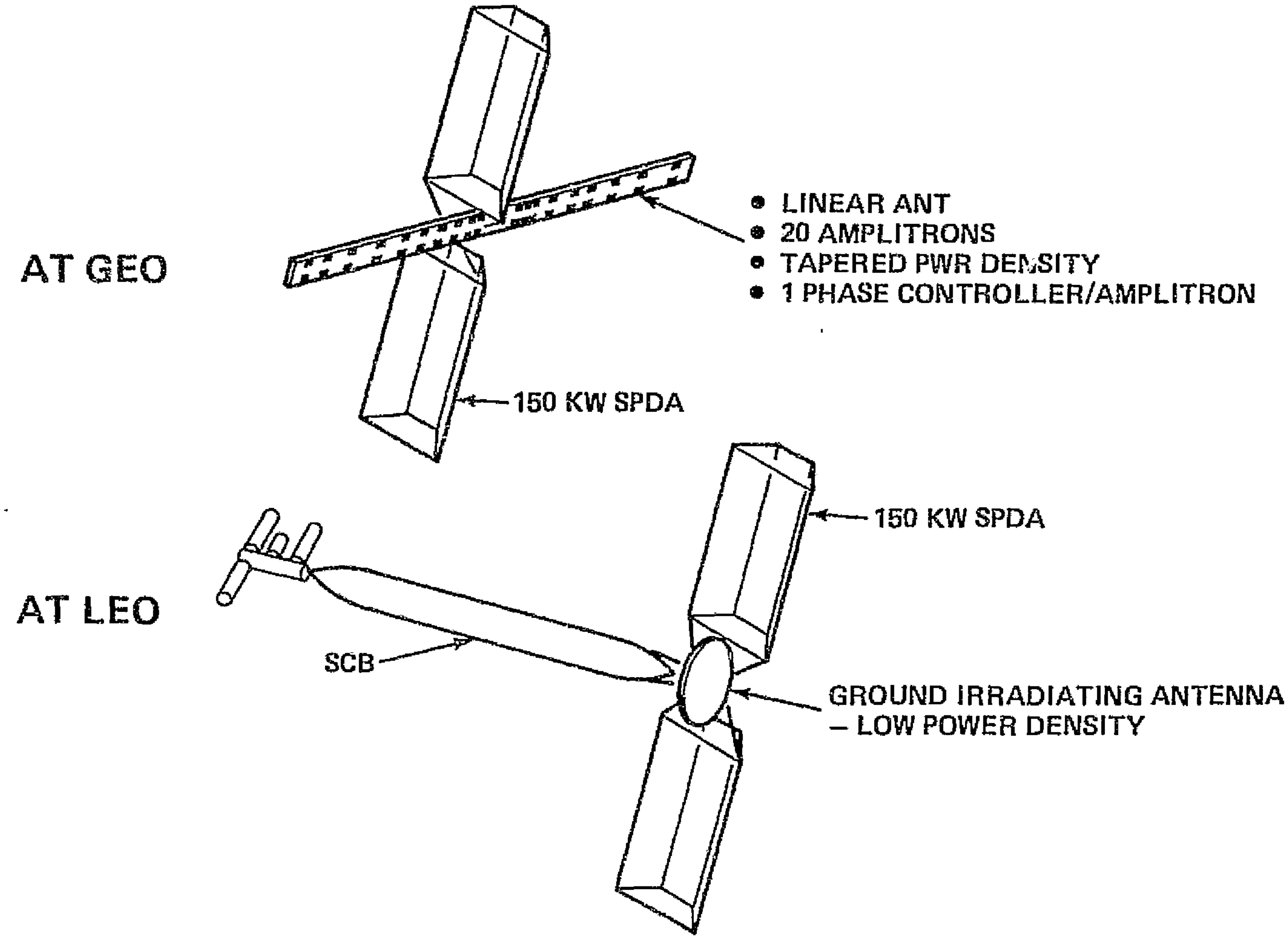
After being sortie built in LEO and used as a free flying development article, the 150 kw SPDA has further possible use apart from its presently baselined use as the power source for the SCB.

One possibility is to attach a linear microwave antenna to it, as shown in the sketch. The antenna is 105 m long and has 20 amplitrons of 100 kw rf output, each mounted on a waveguide. The waveguides decrease in size towards the antenna center, which allows simulation of the full size SPS antenna power transmission characteristics. Attachment of the antenna is done in LEO and the assembly then transported to geostationary. In GEO, the antenna transmits to a rectenna on earth. It is controlled by a ground based reference signal. This use of the SPDA requires development of another power source for the SCB.

An alternate use for the SPDA is to attach it to the SCB as the power source but to add a microwave antenna for transmittal to either a ground or an in-orbit rectenna. The in-orbit rectenna would be the same as for the 2 mw SPDA described elsewhere. Transmittal to the ground, as a demonstration, would provide low power for three or four minutes during each of two orbits per day. The antenna is high frequency and requires development of amplitrons, different from those developed for SPS.

G-379

ALTERNATE DEVELOPMENT TACTICS FOR 150 KW SPDA



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G-379

GRUMMAN

2 MW SPDA LEO DEVELOPMENT OPTIONS

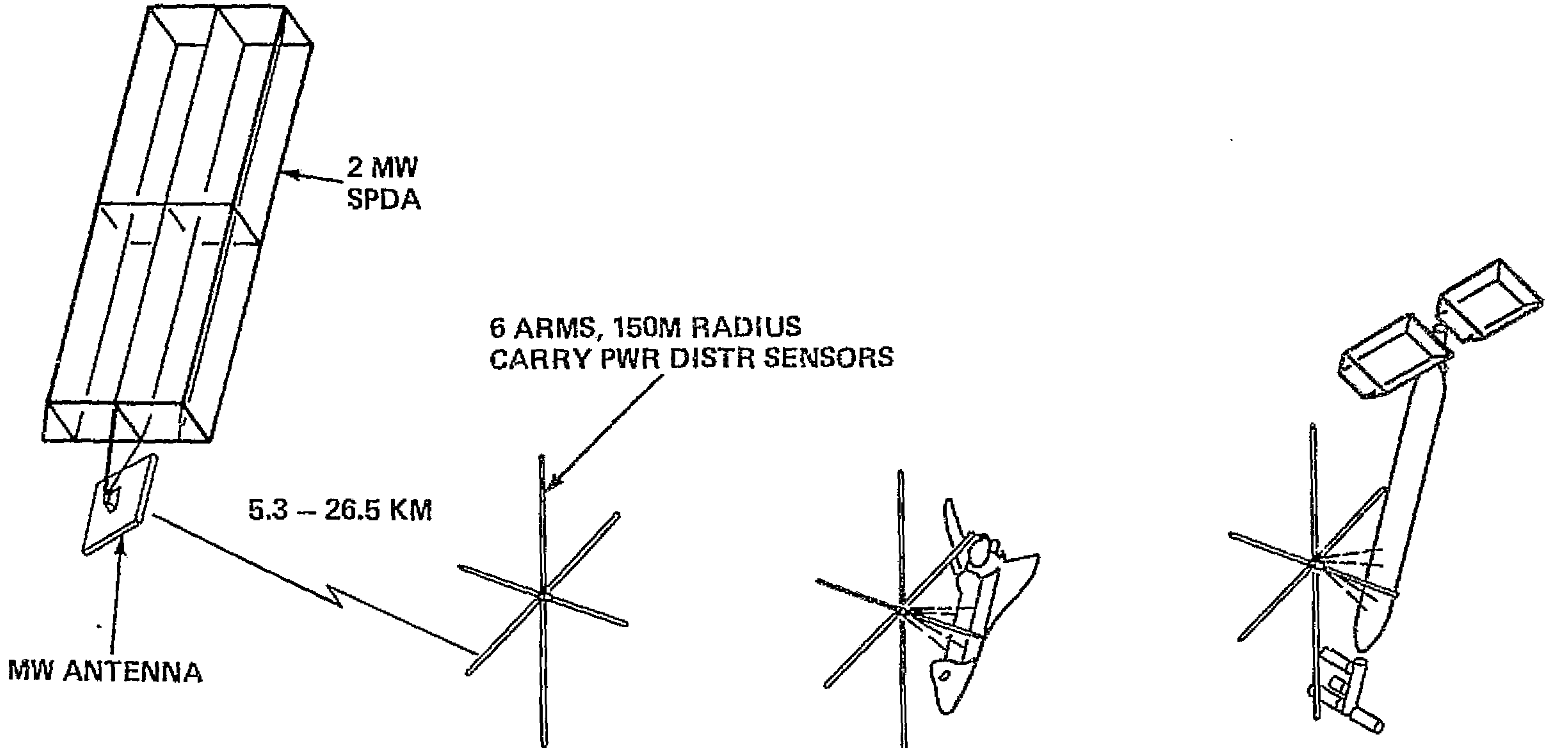
Operational orbit for the 2 mw SPDA is baselined as geostationary. An alternate for those program options which build the SPDA in LEO is to operate it in that orbit, thus saving transportation to GEO costs.

Power transmission from LEO to one ground rectenna gives reception for approximately four minutes during each of two orbits per 24 hr. The figure shows LEO to LEO transmission with a rectenna and the SPDA in the same orbit, but between 5.3 km and 26.5 km apart. The basic rectenna has six, equally spaced, 150 m long arms radiating from a central hub. Power distribution sensors are mounted on the arms to monitor the microwave pattern from the transmitter. The central hub contains electronic subsystems and mounts a central wave front coordinating antenna facing the transmitter.

Three alternate concepts are shown for the rectenna. It can be a free flyer, in which case it will need a solar array for power and recording and stationkeeping subsystems. The orbiter can be flown on a sortie mission with the rectenna mounted to it. It is thought that orbiter structure provides sufficient microwave protection for the crew. A third alternative is to mount the rectenna to the SCB. Again, structure will protect the crew.

G-380

2 MW SPDA LEO DEVELOPMENT OPTIONS



RECTENNA: ——— FREEFLYER ——— ATTACHED TO ORBITER ——— ATTACHED TO SCB

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GRUMMAN

G-380

LEO SCB RESPONSE TO VARYING SPS CONCEPTS

The effects on the LEO SCB of three candidates SPS concepts are considered.

With the photovoltaic system, three types of solar cells and concentration ratios are shown. As the concentration ratio increases, so does the requirement for precision of concentrator geometry and pointing accuracy.

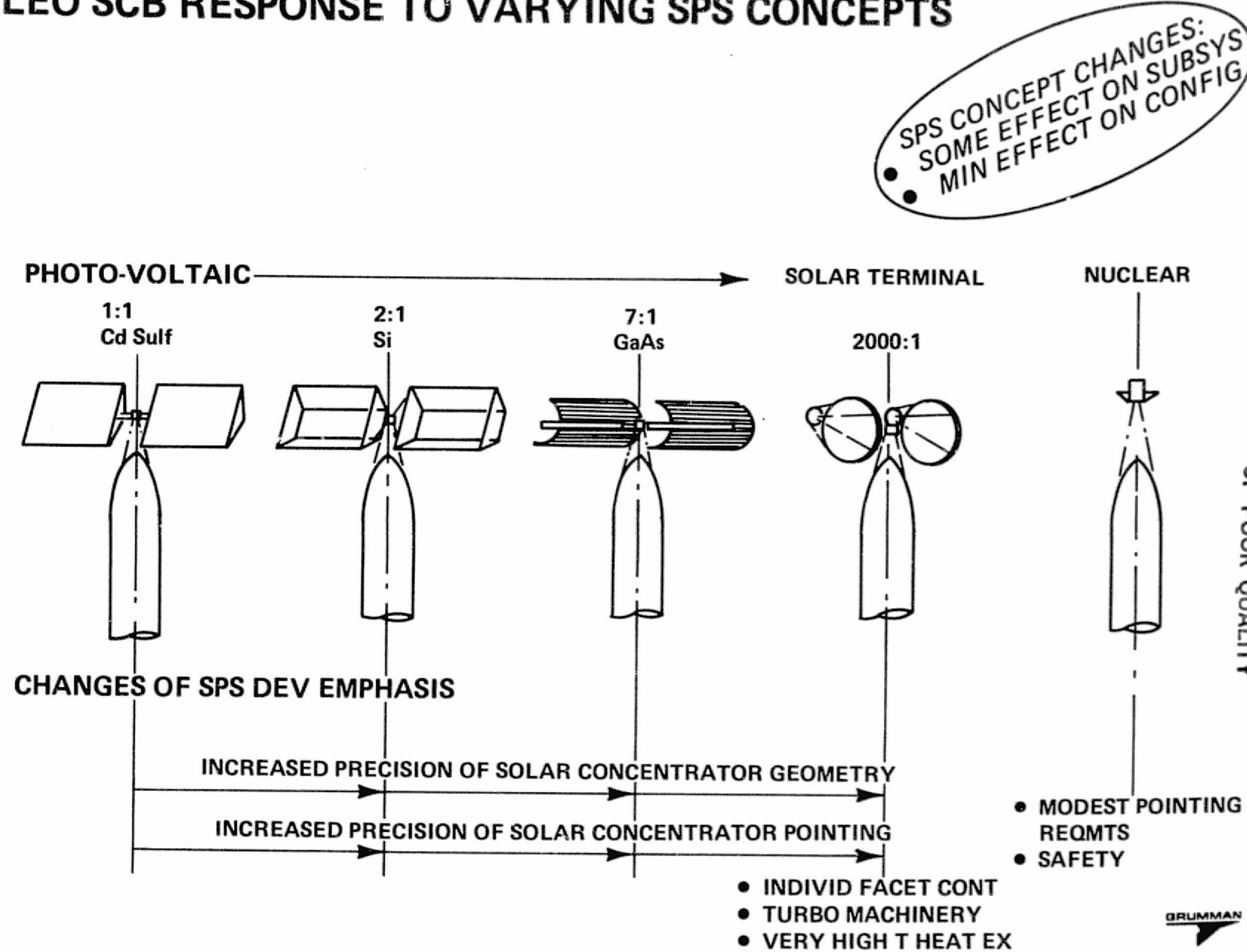
The solar terminal system requires even higher precision of concentrator geometry and pointing accuracy. Additionally, for optimum performance, the system requires individual control of the concentrator facets. The necessary turbo machinery is a weight and cost penalty as is the problem of very high thermal heat exchange.

Nuclear powered system has no pointing requirements but creates a safety problem.

These considerations impact the selection of which concept to use on the SCB but their overall impact on the configuration is minimal. There is a greater effect on subsystems but it is not an apparent driver.

G-335

LEO SCB RESPONSE TO VARYING SPS CONCEPTS



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G-335

SPACE CONSTRUCTION BASE GEOSTATIONARY ORBIT – OPTION 2A

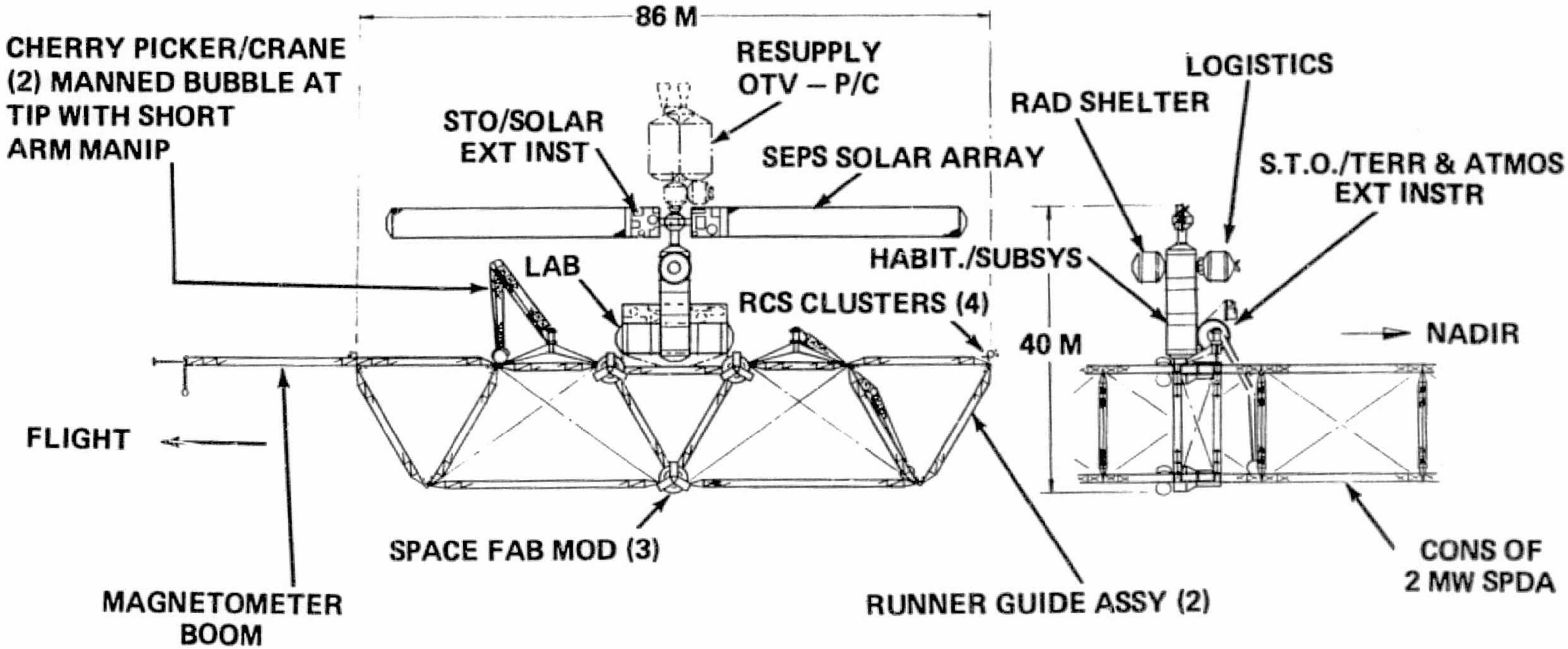
This program option requires that the 2 mw SPDA be constructed in geostationary orbit. The construction base is built in LEO with the help of the Initial Construction Base then transported to its geostationary operational orbit by OTV-P/C. Operational flight attitude and direction are shown on the figure.

The construction part of the base is configured primarily to build the 2mw SPDA. Later, the PSP antennas No. 2 and No. 3 are built and will require such additional facilities as turntables. Construction of the 2 mw SPDA follows the procedures described elsewhere for construction by the LEO Advanced Construction Base. This base provides similar space fabrication modules and runner guides. There are two, fixed mount, crane facilities each comprising an articulated arm with a pressurized bubble at its tip. Each bubble houses a shirtsleeve crew member operating short arm manipulators to make structural joints, etc. The manipulator docks the bubble to the habitation module for the operator to "go home". Power is provided by a SEPS two winged solar array mounted on a two axis gimbal to track the sun.

A combined habitation and subsystems module provides the necessary accommodations and subsystems for a crew of three and for station operations. A laboratory module houses STO internal instruments and electronics, some life sciences capability to monitor the performance of the crew and equipment for SPS development and construction test samples. An external platform mounts STO terrestrial and atmospheric instruments to look along the local vertical. STO solar instruments are mounted on another platform adjacent to the solar arrays which gimbals with the arrays to track the sun. Docking of the OTV-P/C for crew rotation and logistics resupply is provided outboard of the solar array mounts with a connecting tunnel to the habitation module for shirtsleeves crew transfer. The full and empty logistics modules are exchanged by the cranes. A shelter is provided for crew protection from solar flare radiation.

G301T

SPACE CONSTRUCTION BASE
GEOSTATIONARY ORBIT - OPTION 2A



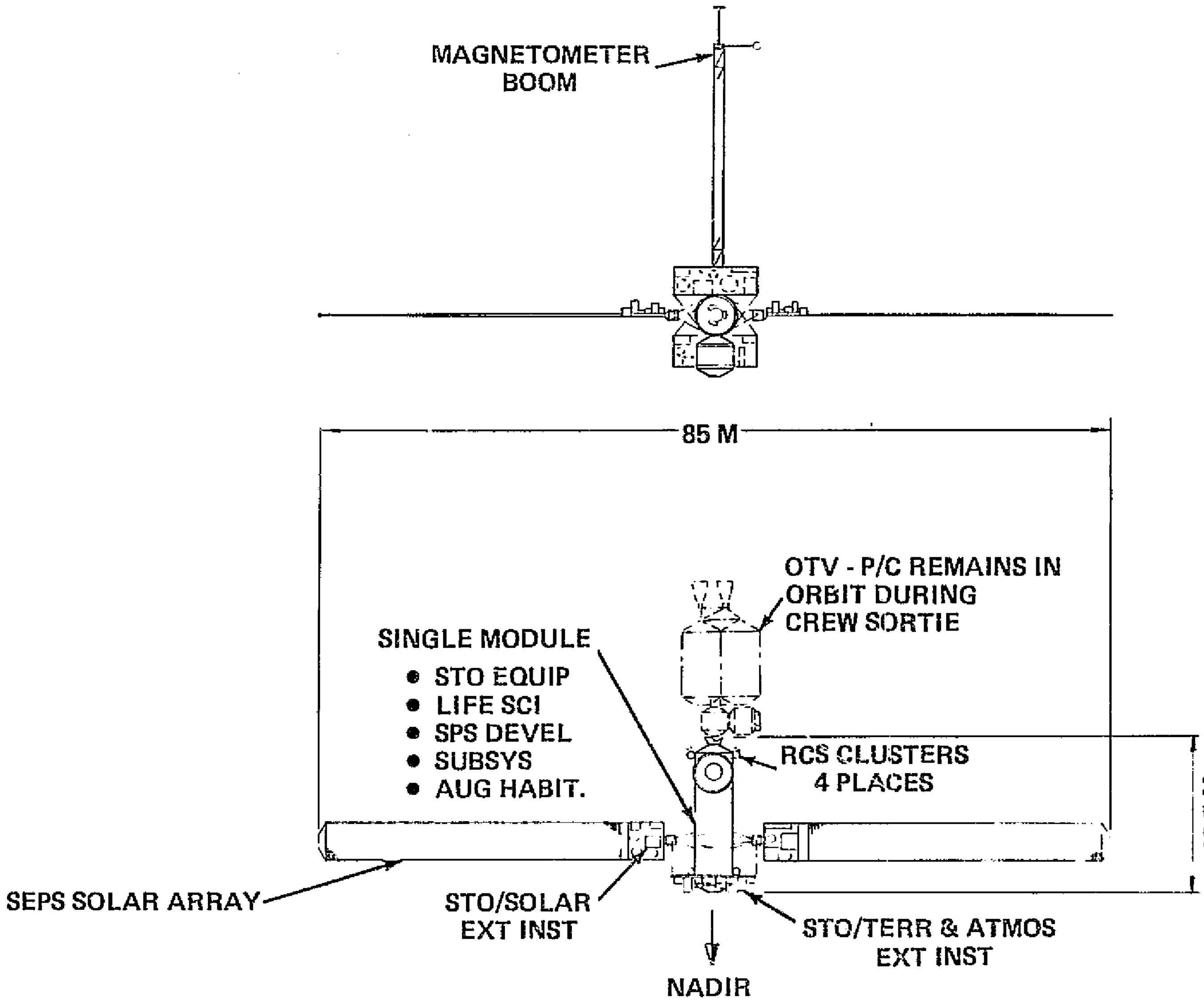
GRUMMAN

OUTPUST GEOSTATIONARY ORBIT – OPTION 2B

Program Option 2B calls for the SPS to be built in geostationary orbit. The effects on man of the environment at this orbit will be an input into the "go/no go" decision to pursue this option. The Outpost provides a relatively low cost housing for man to check these effects over a time period.

The manned mission is a long term sortie mission with three men transported in an OTV-P/C which remains in geostationary orbit attached to the Outpost for the duration of the men's stay. The crew transportation module and the Outpost module provide, between them, relatively spartan habitation and subsystems facilities. A logistics module remains attached to the crew module. The Outpost module also provides some life sciences capability to check the crew performance and condition, some mechanical tasks oriented towards SPS development to calibrate crew performance and housing for any STO internal equipment which could usefully be put aboard the Outpost. External to the module is a platform to mount instruments for STO/terrestrial and atmospheric experiments. A magnetometer boom extends from the platform. Adjacent to the solar arrays and mounted on the same gimbal is another platform which mounts STO/solar instruments. Power is supplied by a SEPS two winged array mounted on a single axis gimbal. The other gimbal axis necessary to track the sun is provided by rotation of the Outpost about its local vertical axis. Nadir is indicated on the figure and permits viewing by the STO/atmospheric and terrestrial experiments.

OUTPOST
GEOSTATIONARY ORBIT OPTION 2B



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G-30

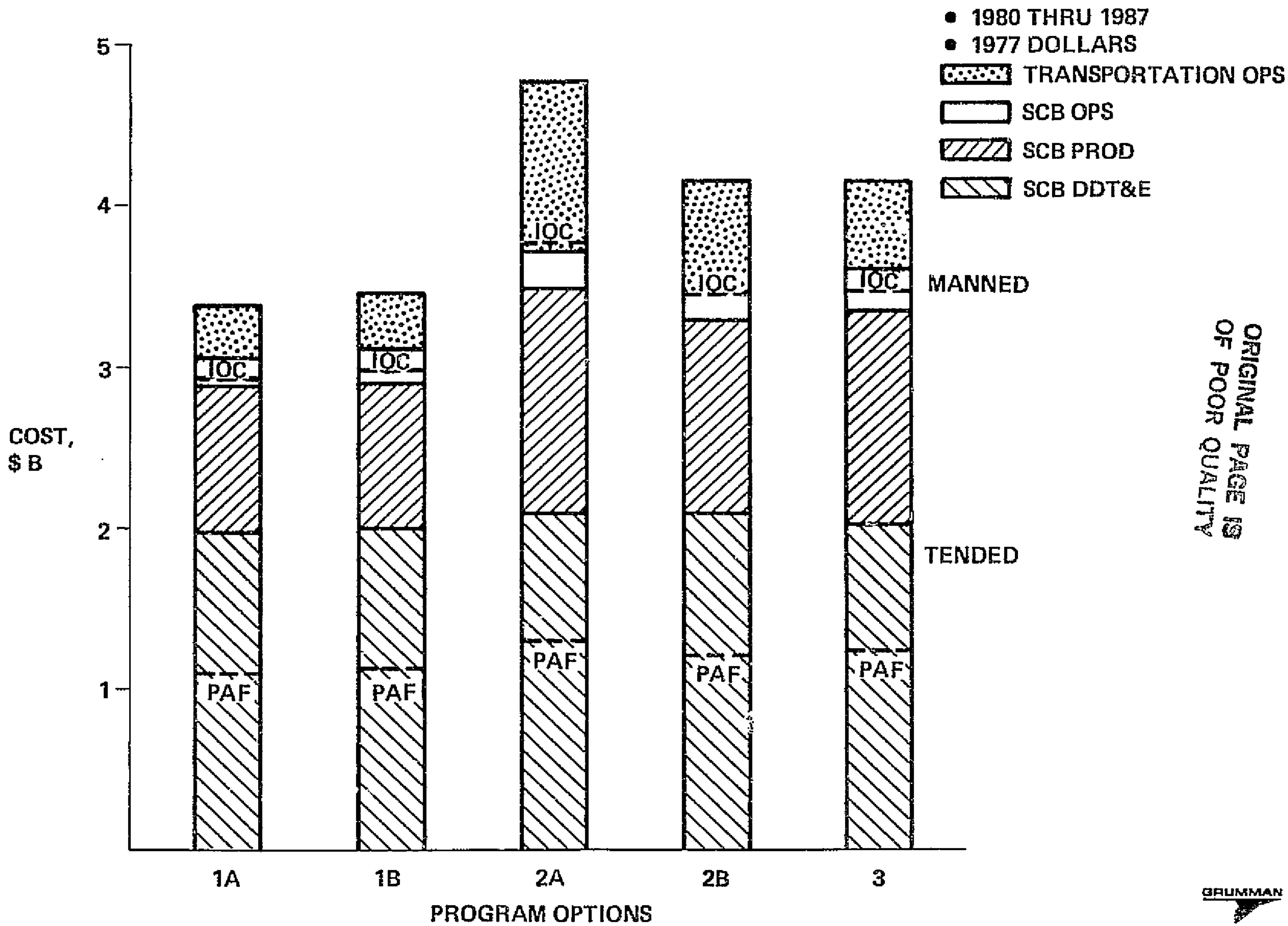
GRUMMAN

SCB PROGRAM OPTIONS COST COMPARISON

The costs directly associated with the Space Construction Base program are as shown. These costs have been divided into SCB DDT&E, SCB Production, and SCB Operation Costs. In addition the transportation costs necessary to implement the missions through 1987 operations are also shown. As a further indicator of cost, the peak annual funding levels are superimposed as horizontal lines for each option. In addition, those costs to initial operational capability are also specified.

K307T

SCB PROGRAM OPTION COST COMPARISON



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GRUMMAN

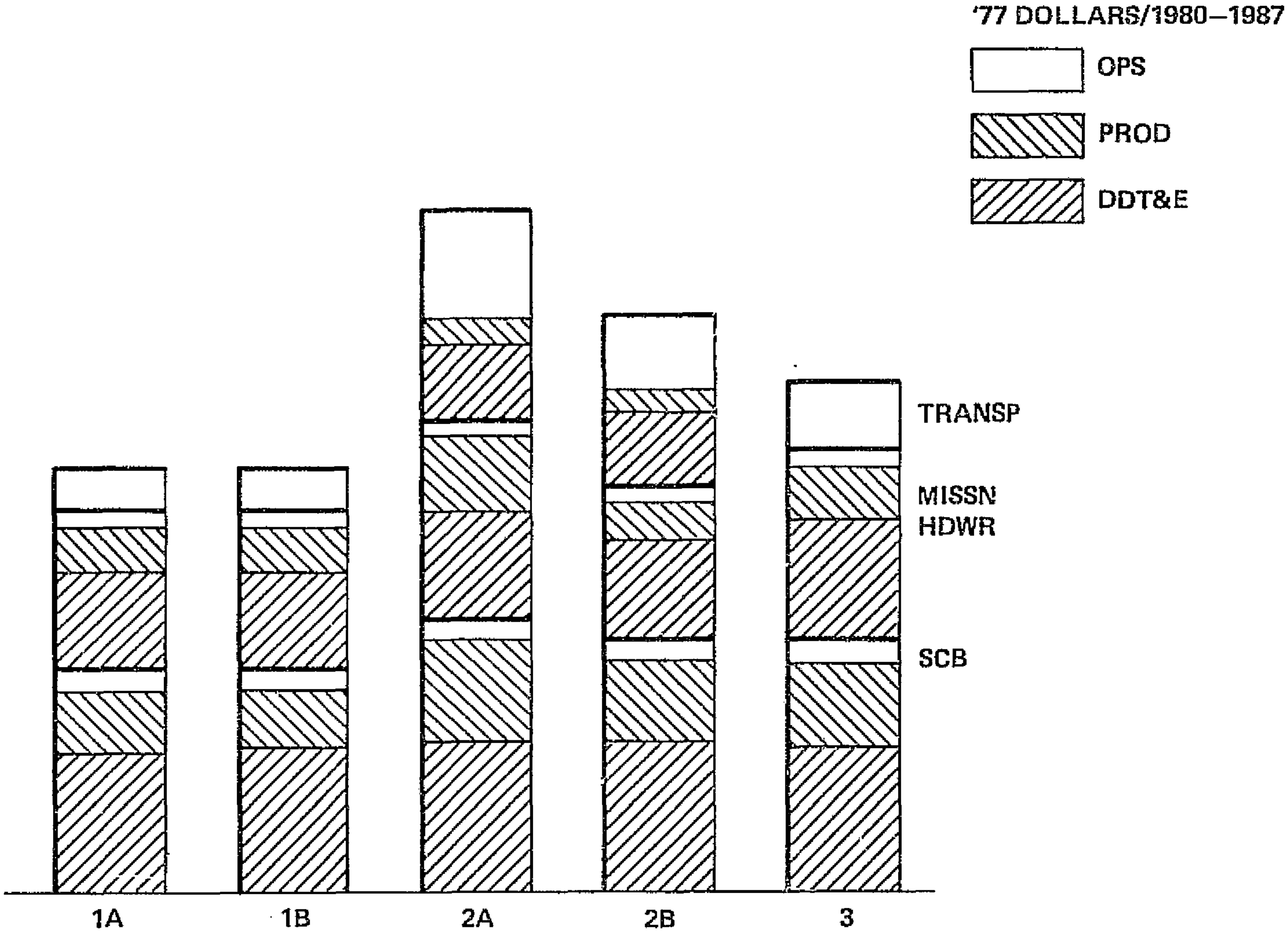
K-307

SPACE STATION SYSTEMS PROGRAM COST COMPARISON

The total manned space program to support each of the program options includes mission hardware and transportation costs above and beyond those costs directly associated with the Space Construction Base development, production and operations. Very preliminary estimates of these costs have been made and are shown on the opposite page. The height of each bar indicates the relative magnitude of the various constituents. Scales have been omitted to reinforce the point. More program definition is required to establish firm absolute magnitudes.

K319T

SPACE STATION SYSTEM PROGRAM COST COMPARISON



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K-319

SSSA CRITERIA FOR PART 2 COMPARATIVE EVALUATION

This comparative evaluation section examines the several program options and evaluates them in terms of the criteria listed on the opposing page.

The first several pages of this section review the program options and the representative configurations.

G425T

SSSA – CRITERIA FOR PART 2 COMPARATIVE EVALUATION

- ENGINEERING COMP
- COST
- TRANSPORT IMPACT
- BUDGET REQMTS
- MISSIONS
- TECHNOLOGY STATUS
- GROWTH POTENTIAL
- PROGRAM FLEXIBILITY

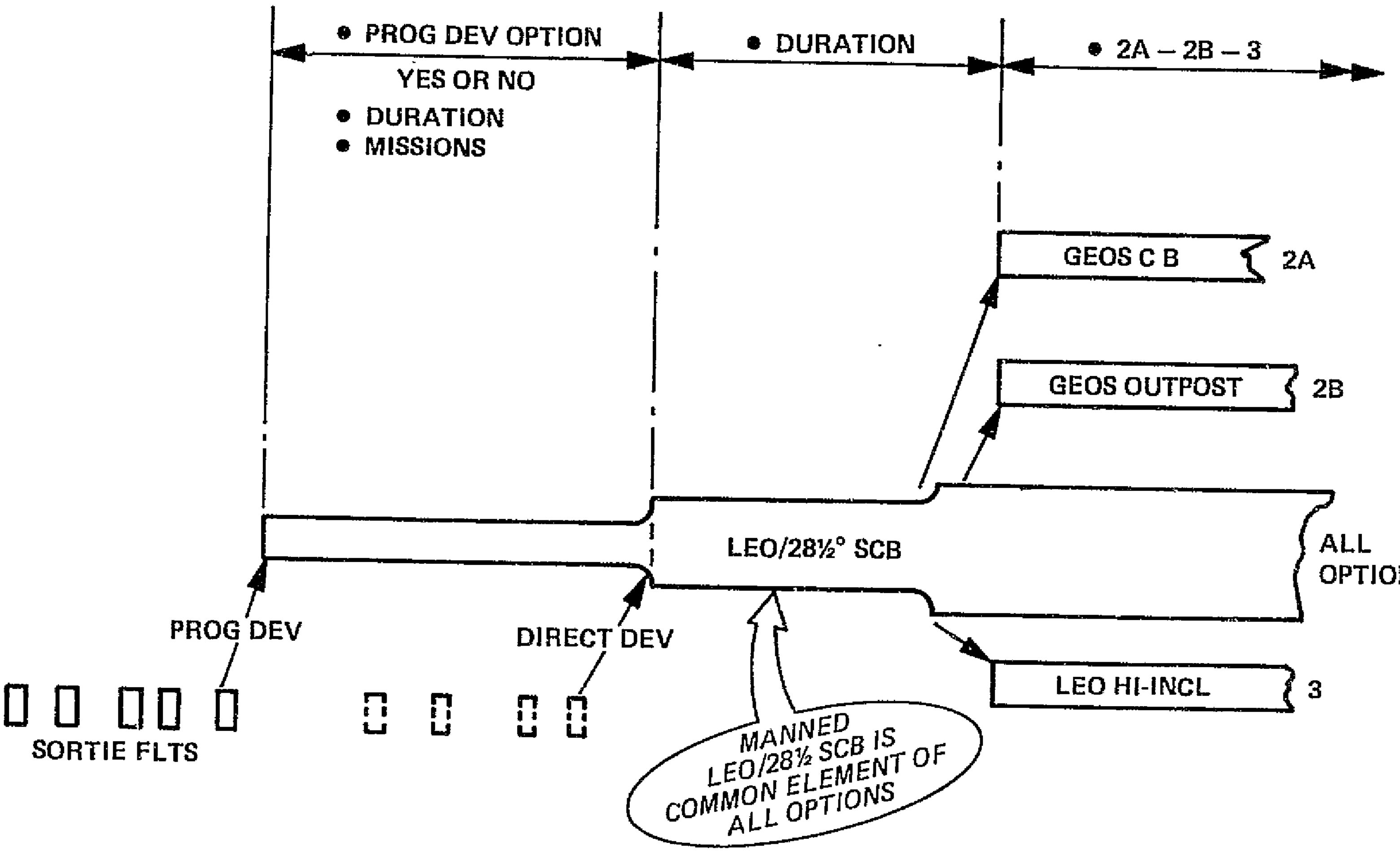
GRUMMAN

AREAS OF PROGRAM FLEXIBILITY

The manned LEO (28½°) space construction base is a common element in all options. Using the progressive development option as a precursor to the initial construction base provides early conformation of the ability to build large structures in space and delays the decision point on other options.

G438T

AREAS OF PROGRAMMATIC FLEXIBILITY



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G-438

RANGE OF SPS ASSY SITE OPTIONS

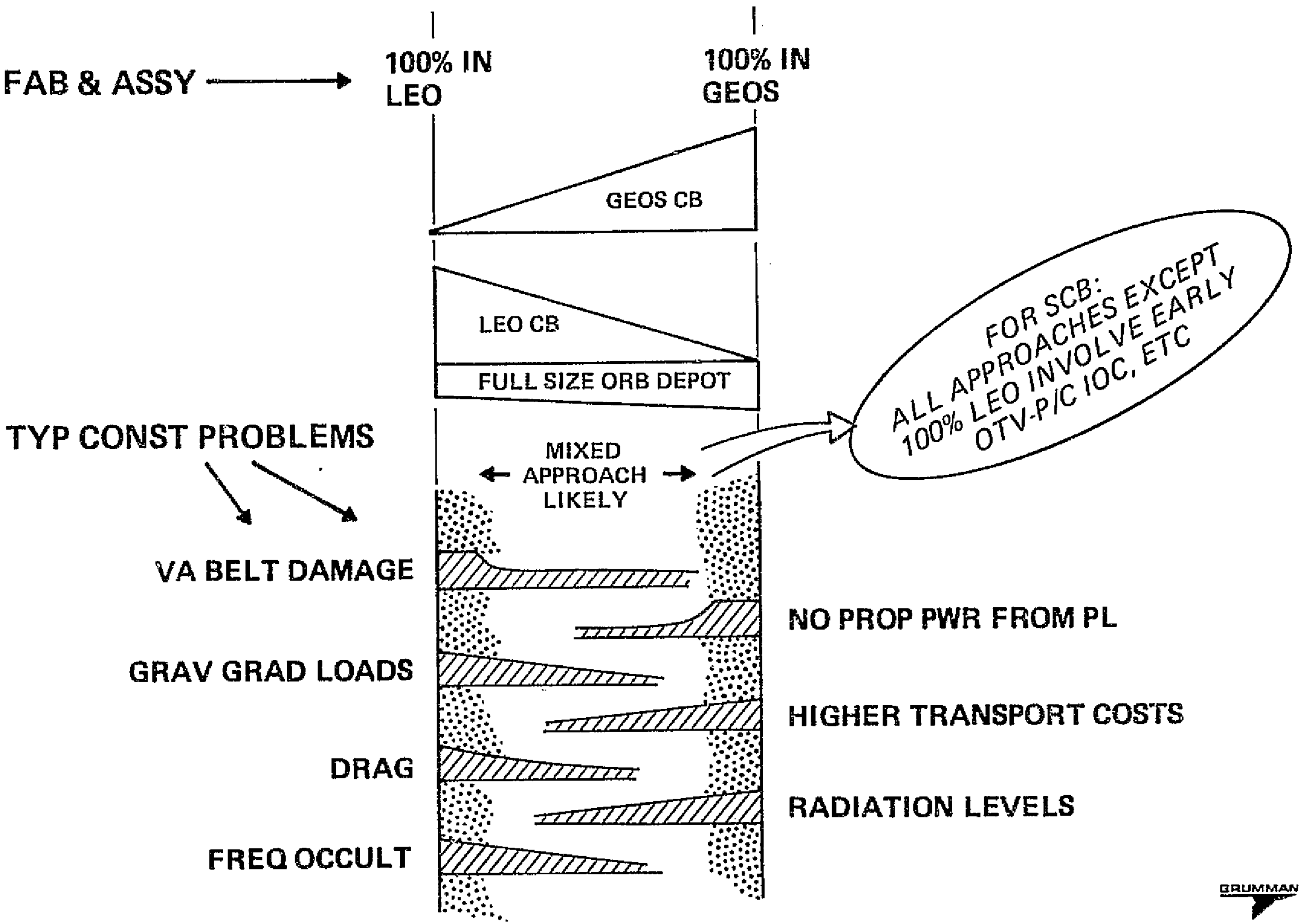
Construction Base sites in low earth orbit and geosynchronous orbit have a strong influence on the program options. Many considerations enter the site selection process. Considering the assembly site for the SPS, present program options locate it in either LEO (Options 1A/B and 3) or geostationary (Options 2A/B). A dedicated SCB located completely in either orbit is impractical and brings such problems as those listed on the chart.

Consider, as an example, the solar array. If the SPS is completed in LEO, then the solar blankets will be operationally in place during transportation to geostationary and subject to deterioration through the Van Allen belt. On the other hand, if the SPS is assembled in geostationary, then the solar array was not available to power the SEPS transportation of the component parts.

Most probably the final solution will be a mixed approach where some construction is performed in low earth orbit and at least final assembly activities will occur in geosynchronous orbit.

G344T

RANGE OF SPS ASSY SITE OPTIONS



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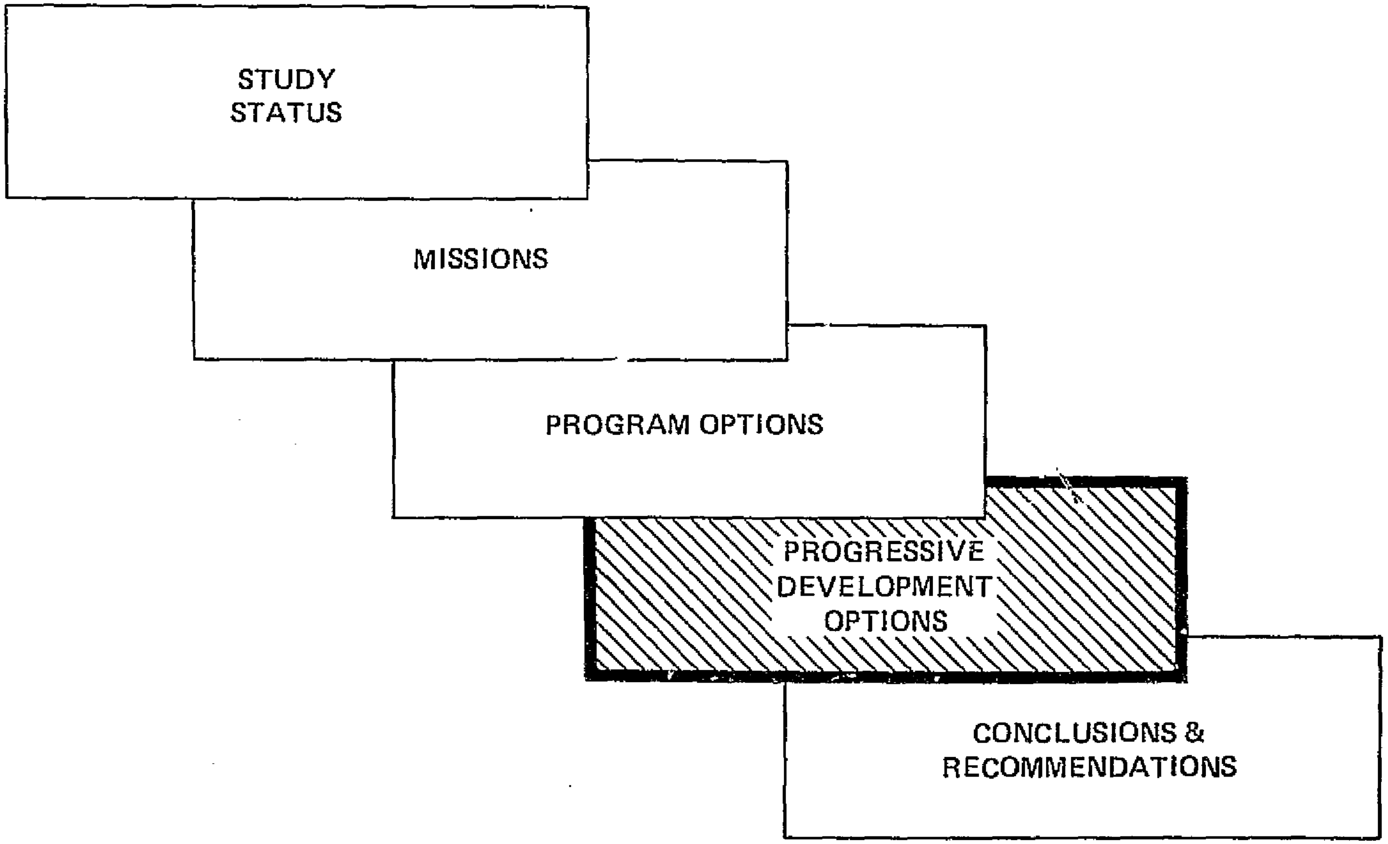
G-344

SPACE STATION SYSTEMS ANALYSIS STUDY PART - 2
PROGRAM REVIEW FEBRUARY 9, 10, 11, 1977
VOLUME 1 - EXECUTIVE SUMMARY

DICK KLINE



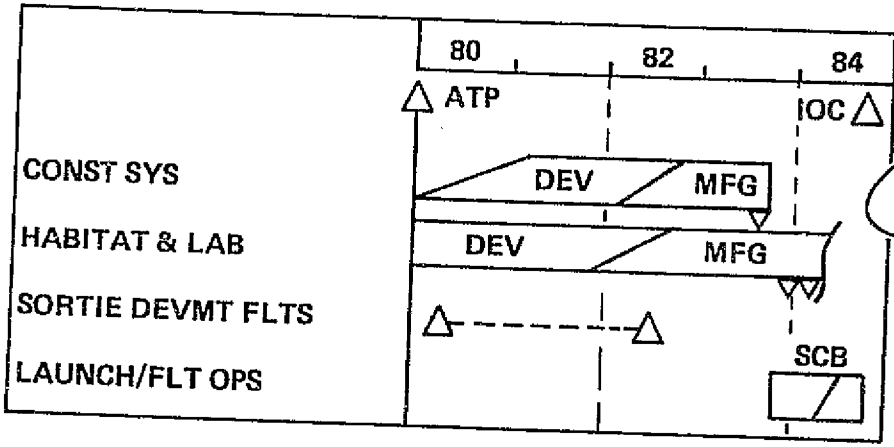
K-315-4

SCB DEVELOPMENT PHASING

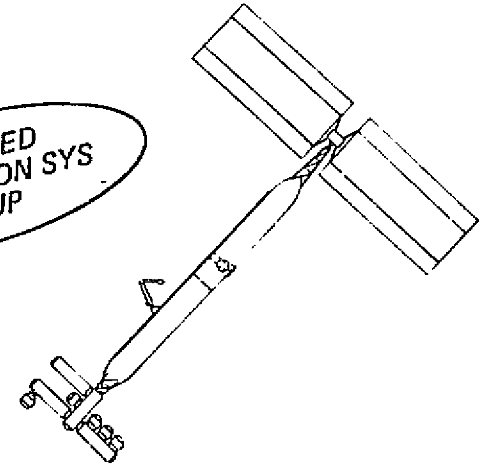
Development of major SCB system elements, such as the construction system and the manned habitat, may be implemented as shown for the SCB fully developed and progressive developed concepts. It should be noted that the baseline construction system includes developed hardware (e.g., STS external tanks, and large structure development automatic fabrication machine) and also uses Shuttle manipulator technology to reduce cost and foreshorten the overall system development cycle. Accordingly, in the fully developed concept the shorter construction system development cycle is keyed to support integrated buildup with the manned habitat. However, in the progressive developed concept development of the construction system is decoupled from the habitat to reduce peak year funding and provide an early Shuttle-tended construction system IOC.

SCB DEVELOPMENT PHASING

FULLY DEVELOPED

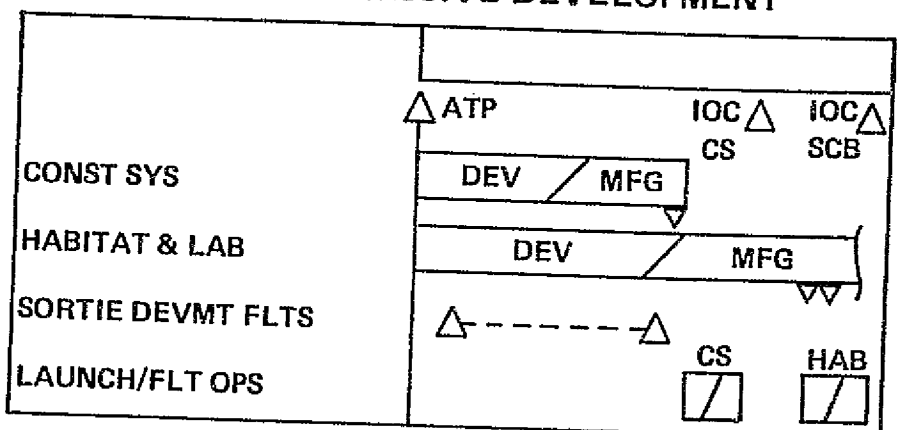


INTEGRATED CONSTRUCTION SYS BUILD UP



DECOUPLE CONST SYS & HABITAT DEVMT TO
- REDUCE PAF
- OR PROVIDE EARLY CONST SYS IOC

PROGRESSIVE DEVELOPMENT



GRUMMAN

MC-309

2-7

SCB DEVELOPMENT CONCEPTS

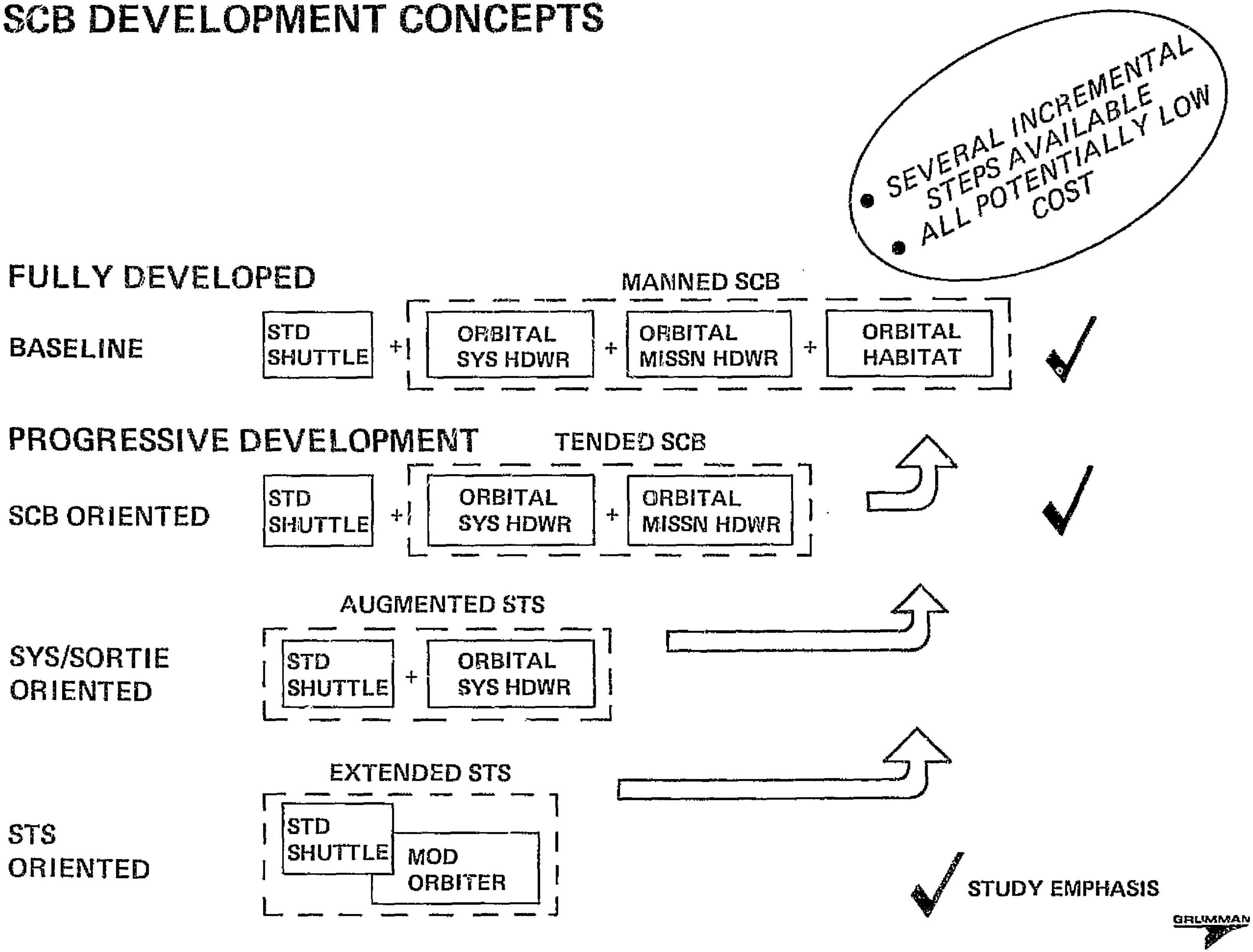
Development and operation of the initial manned space construction base (SCB) can be implemented either by fully developing all SCB system elements at once as in the baseline, or through progressive development and successive buildup of required capabilities.

The facing page defines the fully developed SCB concept together with three progressive development concepts which include SCB oriented, STS/sortie oriented, and STS oriented approaches. Each of the progressive development concepts can lead toward continuous manned SCB operations. The SCB oriented approach bears the closest resemblance to the eventual manned SCB and hence will require fewer steps to complete full development.

The fully developed/baseline concept uses the standard Space Shuttle together with the three system elements needed to perform manned SCB operations. These elements include the orbital system hardware (i.e. station keeping, power, etc.), orbiter mission hardware (e.g., construction platforms, construction equipment, lab equipment, etc.) and an orbital habitat (e.g., crew habitability, common labs, logistics etc.). The SCB oriented progressive development concept is similarly defined except that it excludes the orbital habitat. During SCB progressive development operations the crew will live and work out of the Shuttle. Hence, the SCB will be tended or intermittently manned until the habitat can be added. This study is examining both manned and tended SCB concepts.

The two remaining progressive developed concepts, STS/sortie oriented and STS oriented, are defined with respectively less dependence on orbital system hardware.

SCB DEVELOPMENT CONCEPTS



MC-308

PROGRESSIVE DEVELOPMENT SCB MISSION ACCOMMODATION

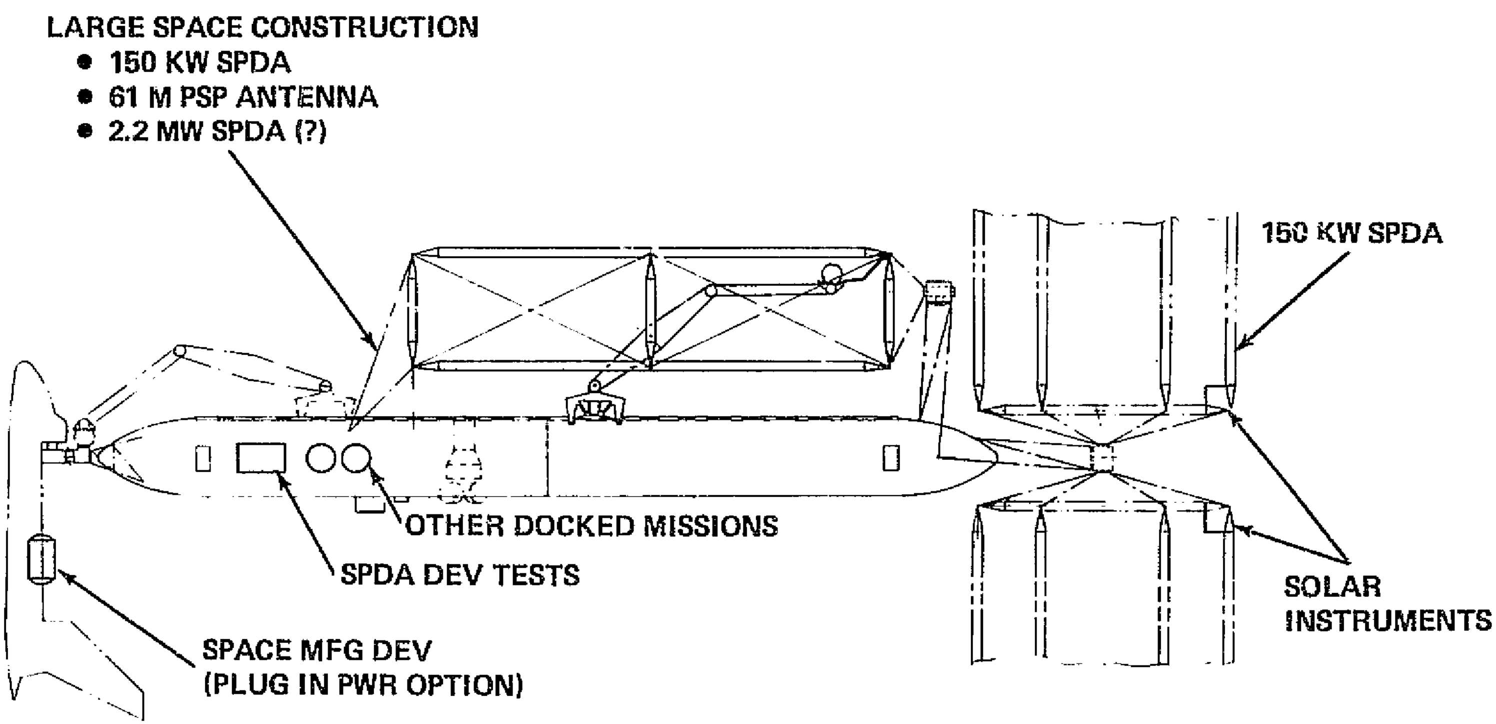
The progressive development SCB configuration can easily accommodate a broad range of missions for tended and untended operations.

As shown on the facing page, this configuration has the same elements for large space construction as the baseline manned initial construction base. Hence, the construction crew will be able to operate from the docked Shuttle in the usual shirt-sleeve Cherry Picker environment. The cherry picker/crane and space fabrication machine are used in conjunction with the required jigs for constructing the 150 kw SPDA and 61 m PSP voice data antenna. In order to construct the 2.2 mw SPDA in the tended mode, however, the construction elements must be upgraded to the advanced construction base configuration.

After the 150 kw SPDA is deployed as part of the SCB primary power subsystem, the excess power can be used to operate a variety of tended- and automated-mission payloads. Typical missions include the automated solar instruments mounted directly on the solar array and the SPDA development test equipment docked to the side of the external tank. Other mission payloads (e.g., LDEF) can also be docked at a number of locations along the External Tanks. Excess power can also be plugged into the Orbiter to augment high power Spacelab payload requirements such as those needed for space manufacturing development. Additional radiator area can also be included to augment Orbiter cooling.

MC-330T

PROGRESSIVE DEVELOPMENT SCB MISSION ACCOMMODATION



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MC-330

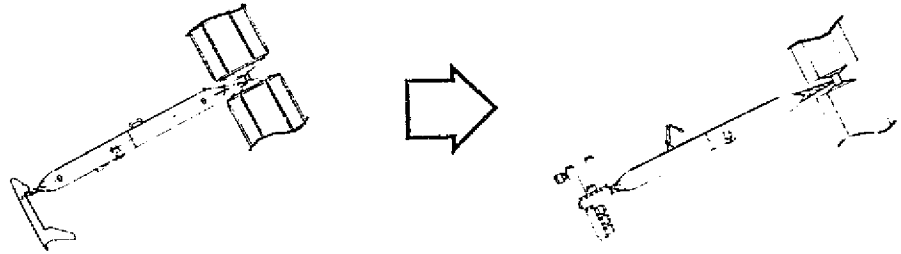
SCB PROGRESSIVE DEVELOPMENT STEPS

The SCB Progressive Development program undergoes five basic steps as it evolves toward continuously manned SCB operations. These progressive steps encompass Shuttle tended flights for construction system assembly, 150kw SPDA fabrication, performing other missions, and assembling manned modules for subsequent manned SCB operations. The progressive buildup of SCB orbital hardware and orderly transfer of Orbiter and SCB mission functions is also depicted on the facing page. For example, at the outset of tended operations the Orbiter provides all mission functions ranging from flight control to logistics/crew transport. As the SCB is progressively developed, these Orbiter tended functions will be included in the SCB.

MC-332T

SCB PROGRESSIVE DEVELOPMENT STEPS

EACH STEP PROVIDES USEFUL SYS CAPABILITIES OPS EXPERIENCE



REQD FUNCTIONS & EQUIPMENTS	PROGRESSIVE STEPS				
	1	2	3	4	5
	ASSEMBLE CONSTRUCT SYS	FAB 150KW SPDA	PERFORM OTHER MISSIONS	ASSEMBLE MANNED MODULES	OPERATE MANNED SCB
SCB					
EXT TANKS/RAILS	–	√	√	√	√
CHERRY PICKER/CRANE	–	√	√	√	√
AUTO FAB MODULE	–	√	√	√	√
DOCKING	–	√	√	√	√
STA KEEPING/AUX PWR	–	√	√	√	√
PRIME POWER	–	–	√	√	√
SUBSYS MODULE	–	–	–	–	√
HABITATION & LABS	–	–	–	–	√
LOGISTIC MODULES	–	–	–	–	√
ORBITER					
FLIGHT CONTROL	√	–	–	–	–
ELECT POWER	√	√	–	–	–
COOLING	√	√	√	√	–
COMM/DATA HDLG	√	√	√	√	–
HABITATION	√	√	√	√	–
MANIPULATOR	√	√	√	√	√
LOGISTICS & CREW TRANSP	√	√	√	√	√

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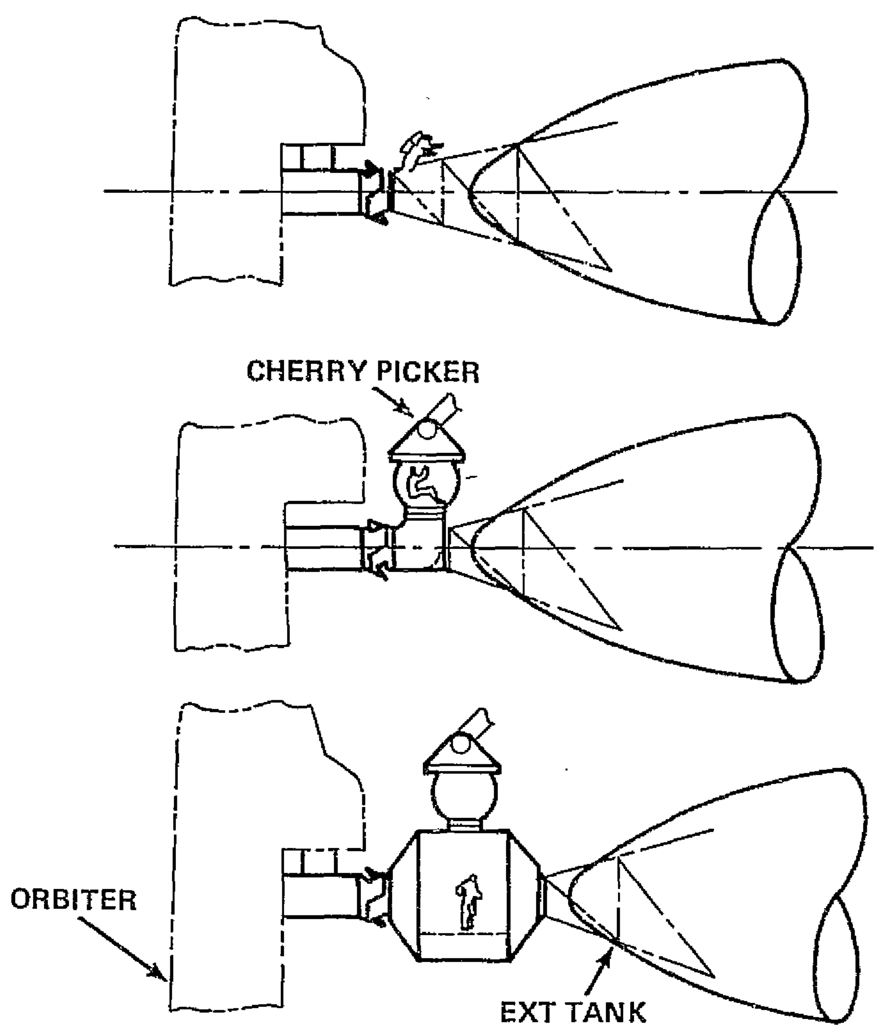
MC-332

TENDED SCB DOCKING OPTIONS

Shown are three docking options that were examined during this phase of the study. The first and most simple uses STS hardware and provides ingress/egress for EVA only. The second option, our present baseline adds an "Elbow" tunnel with an interface to the cherry picker/crane system, providing IVA as well as EVA. The third and more complex system adds a Spacelab type module to augment the living/working space on the STS. This plug-in-lab remains attached to the SCB for repeated use during tended and untended automated mission operations. Additional flexibility of the plug-in-lab can be achieved by the addition of a regenerating life support system and radiators. This will allow repeated STS visits of long duration at little or no penalty to the STS systems.

MC-323T

TENDED SCB DOCKING OPTIONS



- **EVA DOCKING HATCH**
- **IVA/EVA DOCKING TUNNEL**
  - – SHIRT SLEEVE TRANSFER
  - – CONSERVES STS ATMOS
- **PLUG IN LAB**
  - – ADDL LIVING/WORK ROOM
  - – TENDED & AUTO OPS
  - – REGEN ATMOSPHERE
  - – ADDL COOLING
  - – OTHER

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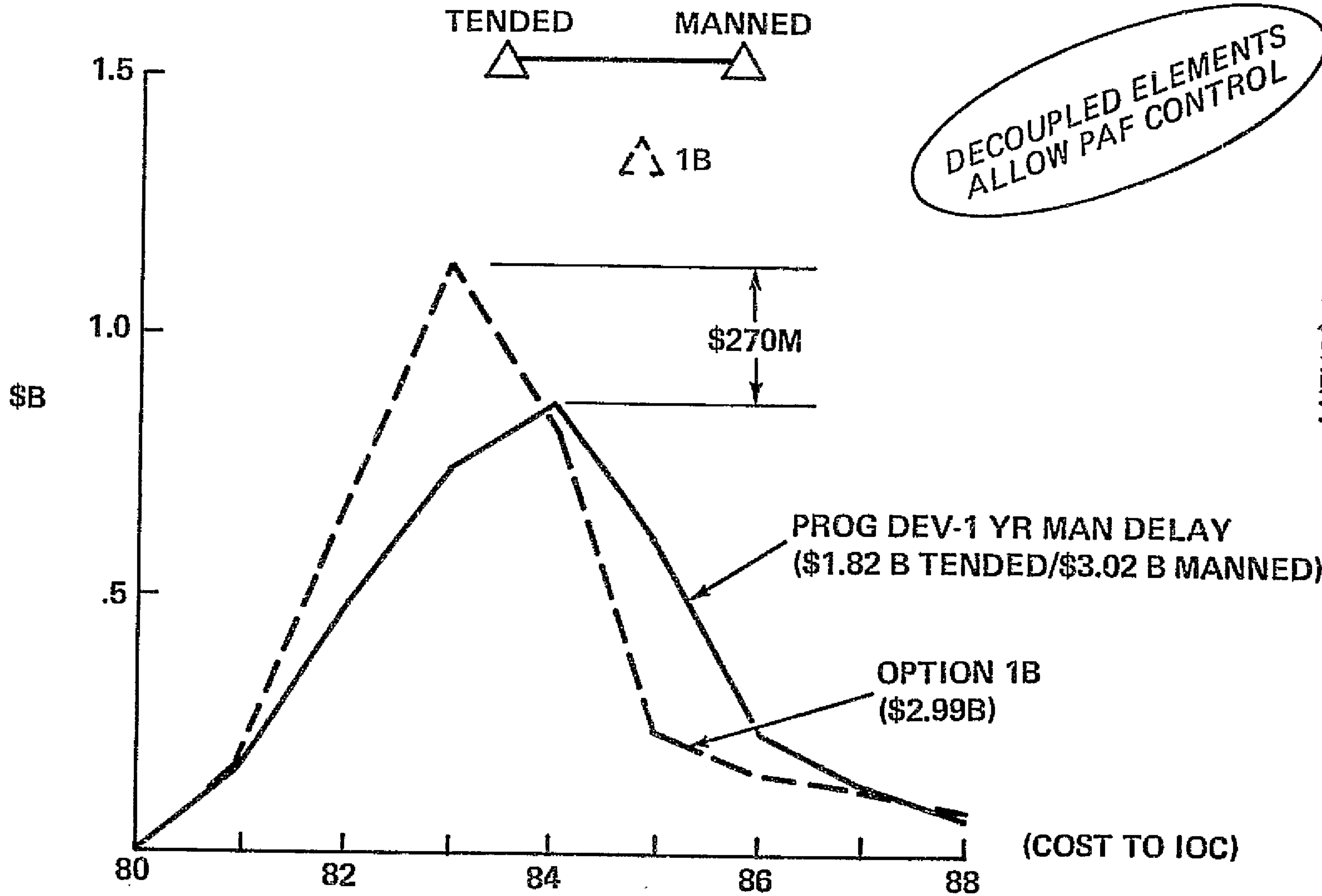
MC-323

SCB PROGRESSIVE DEVELOPMENT FUNDING COMPARISON

The facing page illustrates the difference in fiscal funding requirements for SCB progressive development program versus a fully developed SCB approach exemplified by Program Option 1B. Decoupling the development activities between the SCB construction system and the manned habitability systems allows an early operational capability to be established in concert with lower fiscal costs. By delaying manned IOC for 1 year the tended SCB phase lasts for about two yr. As a result the peak year funding is not only reduced but also delayed.

MC333T

SCB PROGRESSIVE DEVELOPMENT FUNDING COMPARISON



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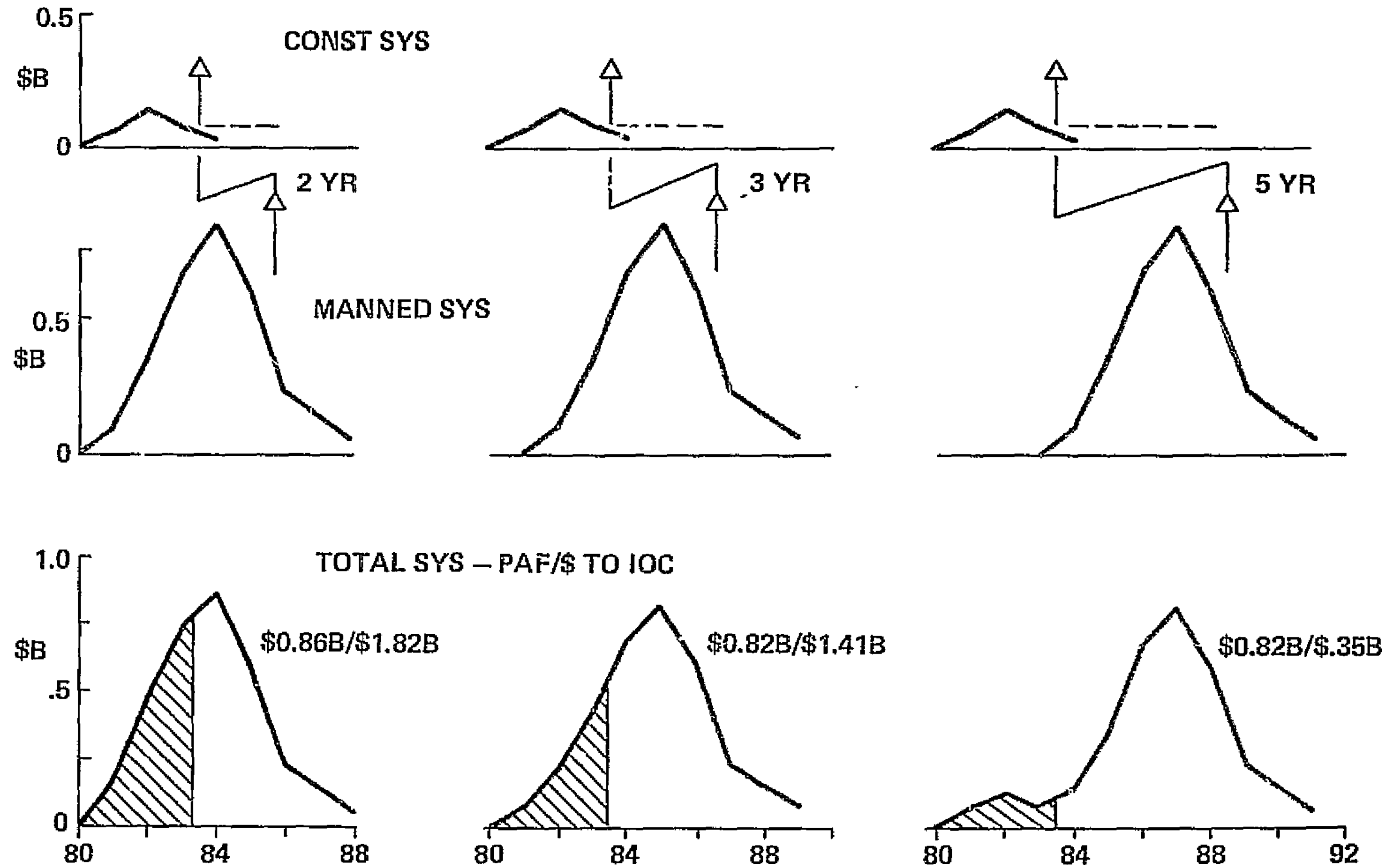
MC-333

PROGRESSIVE DELAY CONTROLS EARLY FUNDING

The SCB construction system represents less than 20% of the total costs required to develop, manufacture, and launch a fully integrated manual SCB. As a consequence, further delay in initial manned systems capability beyond the two-yr, tended SCB phase will only reduce peak year funding to match that required for implementing the manned system elements. This is illustrated on the facing page. The primary advantage of longer tended SCB operations lies in reduced cost to IOC.

MC334T

PROGRESSIVE DELAY CONTROLS EARLY FUNDING



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MC-334

SPACE STATION SYSTEMS ANALYSIS STUDY PART - 2
PROGRAM REVIEW FEBRUARY 9, 10, 11, 1977
VOLUME 1 - EXECUTIVE SUMMARY

DICK KLINE

- STUDY STATUS
- MISSIONS
- PROGRAM OPTIONS
- PROGRESSIVE DEVELOPMENT OPTIONS
- CONCLUSIONS & RECOMMENDATIONS

PART 2 SPACE CONSTRUCTION BASE MISSION CONCLUSIONS

The Space Construction Base program is not an end in itself but rather a means for accomplishing various manned space missions. With today's priorities, the manned space missions which offer a clear benefit to our lives on earth will gain broad support and it is this theme which should be developed for the Space Construction Base program. Four prime missions which the Space Construction Base can serve are Solar Power Development, Space Manufacturing, Public Service Functions and Science Missions such as the Solar Terrestrial Observatory which offer substantial benefits here on earth.

The Solar Power Development Mission drives the Space Construction Base concept schedule and cost. Since the development steps of solar power are many, it is important to identify near term activities and results so that valuable outputs will be obtained along the way and a dead ended program can be avoided. There are several ways to make this development concept happen, such as using early solar power development equipment to generate useful power in space for the Space Construction Base itself, or for other space power needs. The fabrication and assembly equipment can be used to construct other large structures such as antennas for more immediate applications.

Space Manufacturing offers considerable promise as an added function of the Space Construction Base. In our study we have developed a definition of some of the potential benefits of tissue culturing and electrophoresis processes for supporting the manufacturing of valuable Bio/Pharmaceuticals. We have also applied the directional solidification process to manufacture of permanent magnets in space. The benefits from these three processes, tissue culturing, electrophoresis and directional solidification illustrate the potential of Space Manufacturing. Many more processes and applications will evolve. We have defined a submodule space manufacturing approach to accommodate these growing needs. Provisions for crystal growth have been added to the Space Construction Base to illustrate this concept flexibility.

The Public Service Platform concept makes possible communication and observation services from a single multi-purpose satellite. Economy of development, production and maintenance can be obtained by this approach.

The basic new need which emerges on consideration of the Space Construction Base missions is for the capability to fabricate and assemble large space structures.

PART 2 SPACE CONSTRUCTION BASE MISSION CONCLUSIONS

FAB & ASSY OF LARGE SPACE STRUCTURES IS A BASIC NEW NEED

- SOLAR POWER DEVELOPMENT –
  - COMPELLING NEED & MAIN SCB DRIVER
  - BETTER DEFN OF DEVMT STEPS NEEDED
    SEVERAL AVENUES TO AVOID DEAD ENDED DEVELOP
- SPACE MFG – FOUR PROMISING PROCESSES STUDIED:
  - TISSUE CULTURING – EXPTL VERIF NEEDED FOR BIO/PHARMACEUTICAL GROWTH INDUSTRY
  - ELECTROPHORESIS – APPLIC TO BIO/PHARMACEUTICALS
  - DIRECTIONAL SOLIDIFICATION – PERMANENT MAGNET APPLIC
  - CRYSTAL GROWTH – ILLUSTRATIVE OF ADDL SCB SUPPORT CAPABILITIES
- PUBLIC SERVICE PLATFORM
  - BROAD RANGE OF NEW POSSIBLE COMM/OBS SERVICES
- SOLAR TERRESTRIAL OBSERVATORY – SCIENCE MISSION WITH GREAT BENEFIT POTENTIAL

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PART 2 SCB PROGRAM OPTIONS CONCLUSIONS

Concepts have been derived to implement each of the program options defined for the Part 2 study. Detailed integrated requirements were derived as a foundation for the concept development. Programmatics and costing were then developed.

Reuse of the External Tank as the Space Platform was found to be an attractive approach for low earth orbit space construction activity.

An initial low earth orbit Space Construction Base is an excellent point of departure to implement any one of the program options studied. The concepts as developed feature module commonality between all three options although interior rearrangements are needed to suit specific applications.

Since 80% of the deployment costs are associated with permanent manned occupancy in space, this leads to consideration of Progressive Development Options which defer these large costs.

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PART 2 SCB PROGRAM OPTIONS CONCLUSIONS

INITIAL LEO SPACE
CONSTRUCTION BASE
PRESERVES ALL 3
PGM OPTIONS

- DETAILED INTEGRATED REQMTS DERIVED
- PRACTICAL CONCEPTS EVOLVED TO PERFORM EACH OPTION
  - REUSE OF EXTERNAL TANK FORMS AN EFFECTIVE SPACE PLATFORM FOR CONSTRUCTION ACTIVITIES
  - 400 KM ORBIT SELECT. SAVES ONE DEPLOYMENT (13→16M MODS)
  - CONFIG SHAPING FOR GRAVITY GRADIENT & WEATHER VANE FLT CONTROL
  - MFG DEVELOP LAB W. SUB MODULES FOR FLEXIBLE SPACE MFG
  - APPARENT MODULE COMMONALITY BTWN ALL 3 OPTNS WITH INTERIOR ARRANGEMENT VARIATIONS
- 55° LEO INCLINATION FOR STO MISSION ADDS $500M TRANS COST
- ACCELERATED TRANS COSTS IS REAL ISSUE FOR EARLY GEO OPS
- 80% OF DEVELOP COSTS FOR PERMANENT MANNED SUPPORT LEADS TO PROGRESSIVE OPTION CONSIDERATION

PART 2 PROGRESSIVE OPTION CONCLUSIONS

We have studied a Progressive Development Option which accomplishes useful space construction missions from a Space Construction Base which is occupied only when the Shuttle is present. The External Tank work-bench approach is incorporated. The configuration grows with time in space so that more and more of the Space Construction Base features are added. Eventually a fully manned Space Construction Base evolves. Costs are kept low by bringing mission hardware into orbit and leaving it there.

A Progressive Development time period from one to 3 yr seems desirable. The exact duration de- depends upon peak annual funding requirements vs. schedule constraints for geosynchronous and 'r solar power development needs.

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PART 2 PROGRESSIVE OPTION CONCLUSIONS

MAKE EACH PROGRESSIVE STEP USEFUL IN ITSELF

- EARLY USEFUL SPACE CONST MISSIONS POSSIBLE WITH INTERMITTENTLY OCCUPIED SCB:
  - BRINGS MISSION HDWRE INTO ORBIT ONLY ONCE
  - SPACE FAB ASSY FROM EXT TANK WORKBENCH
  - LONG DURATION EXPTS-ADD-ON TO BASE
  - SPACELAB MODULE ON SCB POSSIBLE FOR PRESSURIZED OPS
- 1 TO 3 YR DEFERRAL OF PERMANENT MANNED OPS PAF VS GEO & SOLAR PWR DEVMT LIMITS

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PART 2 RECOMMENDATIONS

In order to deepen the Progressive Development Option, consideration should be given to the desired budget planning constraints. The objectives which should be satisfied during the Progressive Development time period should be defined and there is a strong interaction between solar power development needs and its affect on the Space Construction Base. The plans of these two programs need closer association.

Space Construction Base emerges as a vital part of future manned space activity.

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PART 2 RECOMMENDATIONS

- DEVELOP SPECIFIC PROGRESSIVE DEVELOPMENT OBJECTIVES BASED ON DESIRED BUDGET PLANNING (OR RANGE)
- ITERATE SPACE CONSTRUCTION BASE AND SOLAR POWER DEVMT PLANS
- DEEPEN PROGRESSIVE DEVMT OPTION DEFINITION & PROGRAMMATICS

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